Appendix 2-A

Beach Accretion in The Waukegan Area

Introduction

Beach accretion is caused by deposition of lake-transported sediments In the Waukegan area, this process has been occurring since the end of the last glaciation. To the north of Waukegan Harbor is the Illinois Beach State Park, whose beach accretion has led to the formation of numerous ridges and dunes, dating back to about 3,000 years ago (Attachment 2-A-1). These ridges can be seen on the 1939 air photo of the Waukegan area (Figure 2-A-1). To the north end of the air photo, the linear beach ridges of the park can be seen. These same linear features can be seen extending into the Waukegan Harbor area, even though the surface has been disturbed by human activities.

Natural beach accretion in the Waukegan area is caused by the longshore currents and wave action along the beach. Most rapid beach accretions are caused by the depletion of southward moving sediments associated with northeast winds. These winds cover long open water distances and consequently produce larger waves. Depending on wind direction, storms can build or erode the beach north of Waukegan Harbor. The beach formation mechanisms documented at the Illinois Beach State Park are also responsible for ongoing beach growth in the Waukegan Harbor area.

Waukegan Harbor

At Waukegan Harbor, beach accretion is accelerated by constructed breakwaters. The north and south breakwaters forming the entrance of Waukegan Harbor were constructed between 1883 and 1885. Within five years, the harbor and two slips were constructed. A breakwater north of the harbor was constructed into Lake Michigan between 1900 and 1904. Construction of the harbor entrance breakwaters and subsequent breakwaters north of the harbor produced a barrier to longshore sediment transport in Lake Michigan.

The longshore current causes sediment within the lake to migrate from north to south along the lake shore, in a zone referred to as the littoral drift or the longshore current zone. The littoral drift zone generally occurs along the shore within areas with water depths up to approximately 6 meters (20 feet). A barrier placed in the littoral drift zone prevents sediment migration and

causes an accumulation of sediments. As a result of this accretion, the beach front advances in the lakeward direction. As the beach front migrates lakeward, the littoral drift zone also shifts.

Shoreline position was traced from aerial photographs of the Waukegan Harbor area for the following dates: July 20, 1939, July 1, 1954, March 28, 1959, September 18, 1961, October 20, 1967, October 10, 1974, November 7, 1981, and April 12, 1988. The Lake County survey map was used to measure the shoreline position for 1861, and a U.S. Army Corps of Engineers map was used for shoreline position measurement in 1908. These measurements provide the location of the shoreline at various times, from prior to construction of the breakwater piers up to the present time. The aerial photographs were brought to a constant scale (1"= 500'), and the shoreline location was referenced to unchanging features on the photographs.

The shoreline remained in a relatively limited zone from 1939 to 1974, as shown on Figure 2-A-2. Between 1939 and 1954, a net beach erosion is indicated by a receding shoreline. However, during the 1970s and 1980s, the shoreline grew by almost 300 feet

Beach Cross Section

Sand and sediment deposits within the littoral drift zone of the Waukegan Harbor area were investigated as part of a study by Shabica and Pranschke (1993). The study showed that sediment deposits in the littoral drift zone are thickest in the Waukegan Harbor area. The report suggests that breakwater piers, such as those used at the harbor in Waukegan, have a significant effect on the deposition of littoral drift sediments causing beach accretion.

The data from the above-referenced study and from borings placed on the peninsula were used to prepare a cross section showing the stratigraphy of Waukegan Harbor, extending below the lake surface (Figure 2-A-3). Average annual lake water levels for each year that beach positions were measured have also been plotted on the cross section. These annual lake level elevations were taken from the Michigan-Huron Hydrograph Home Page, USACE Detroit GLHHB (Figure 2-A-4).

Groundwater Hydraulics

The position of the beach front affects the location of groundwater discharge from the Waukegan Harbor peninsula to Lake Michigan. Groundwater modeling of the Waukegan Harbor peninsula shows that groundwater discharges to the lake within approximately the first 250 feet of the

lakeshore, as discussed in Appendix 2-C. As the shoreline moves, the location of the groundwater discharge to the lake shifts as well.

Two important long-term influences on the groundwater discharge location are beach accretion and lake level changes. Beach accretion was explained and documented above. The long-term record of Lake Michigan water levels is provided in Figure 2-A-4 (elevations in International Great Lakes Datum, 1985). Lake levels have risen and fallen over a range of about 6 feet during the period of record. Given the shallow lake bottom slope in Waukegan (about 100 horizontal to 1 vertical), even a small lake level change can move the shoreline by a significant distance.

A conceptual illustration of the combined effects of beach accretion and lake level changes on the groundwater discharge location is shown on Figure 2-A-5. The discharge zones are delineated for the lower 8 feet of the surficial groundwater zone. These results show a current discharge zone within approximately 250 feet from the shoreline.

In addition to long-term water level changes in Lake Michigan, there is an annual cycle of rise and fall over about 1 foot, along with short-term changes due to weather and seiches. These annual and short-term variations cause small fluctuations in the shoreline. The corresponding groundwater discharge zone shifts have a "fuzzing" effect on the edges of the zone. Thus, Figure 2-A-5 should be viewed as an approximate representation of long-term changes in the discharge zones.

Summary

Beach front position is dependent upon deposition or erosion of littoral drift sediment and water level in the lake at any given time. Human activities, principally the construction of breakwater piers, have accelerated the beach accretion process in the Waukegan Harbor area. The movement of the shoreline affects the location of groundwater discharge into the lake. The groundwater discharge location has moved hundreds of feet over the decades since the WCP was built. Much of eastward growth of the beach took place in the period after closure of the plant at the beginning of the 1970s.

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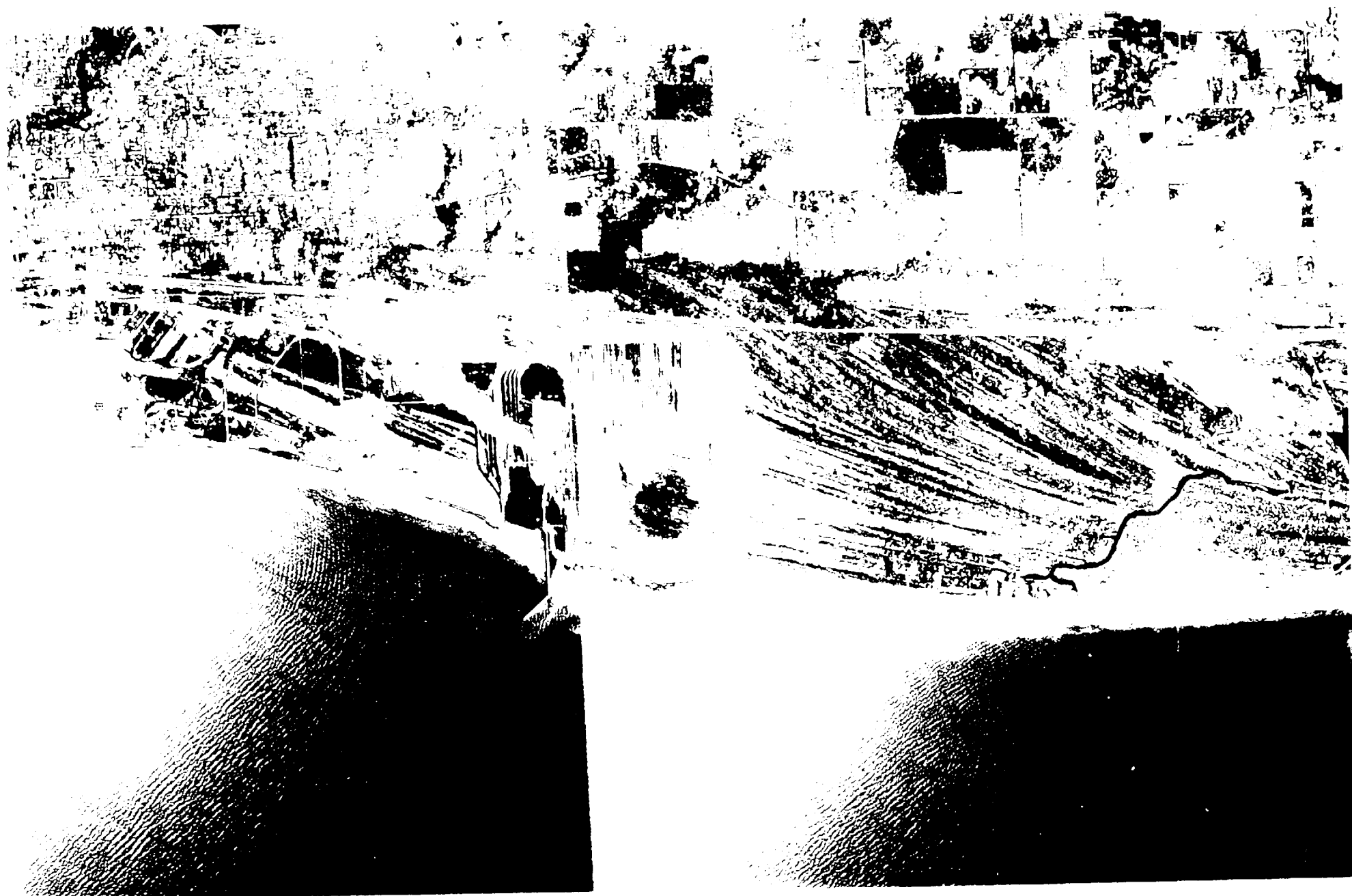
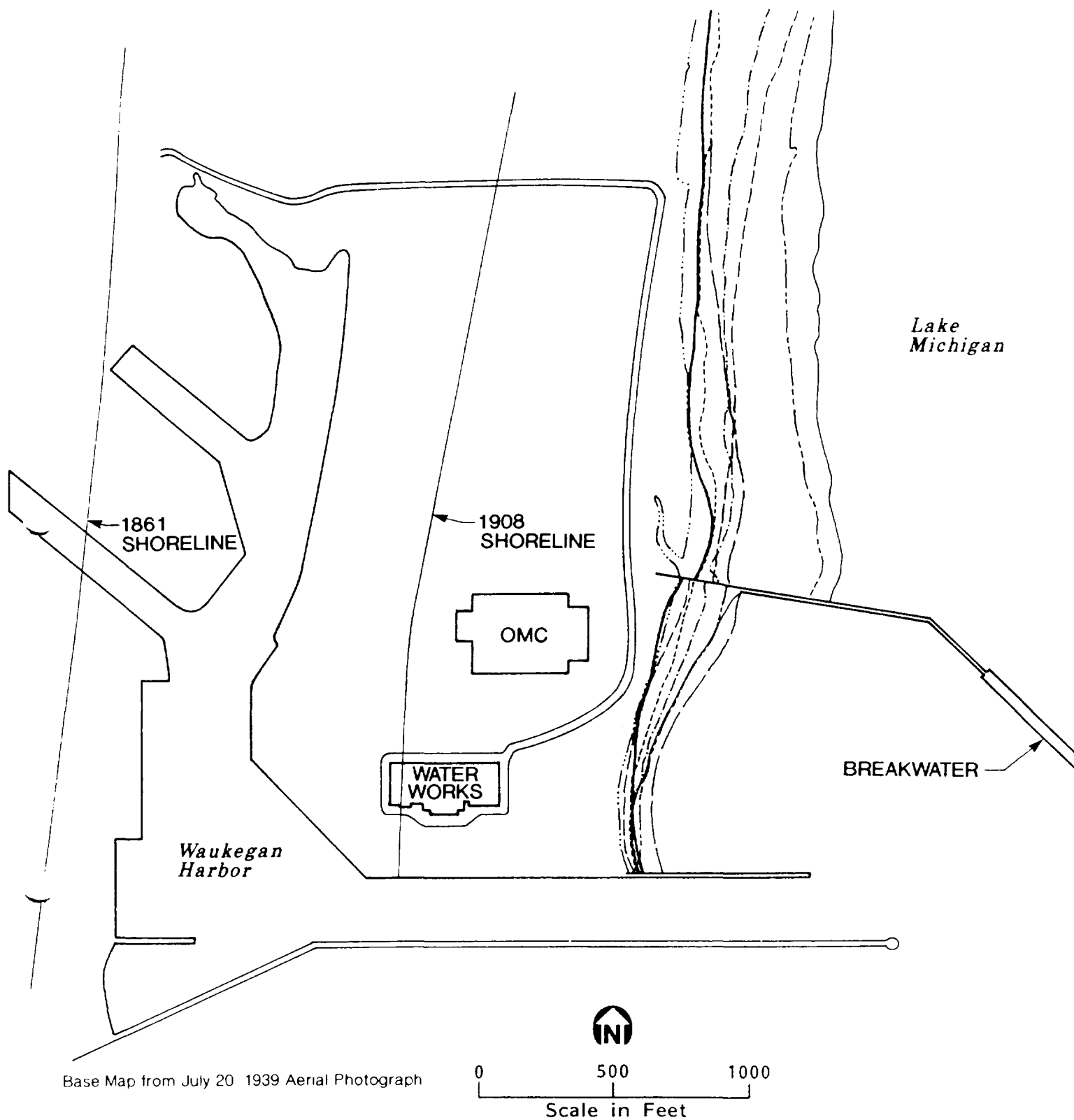U.S. Army Corps of Engineers Detroit GLHHB, Michigan-Huron Hydrograph Home Page.

Aerial Photos dated 4/12/88, 11/7/81, 10/10/74, 10/20/67, 9/18/61, 3/28/59, 7/1/54, 7/20/39.

Lake County Survey Map, 1861.

U.S. Army Corps of Engineers Map, 1908.

1861
SHORELINE

1908
SHORELINE

*Lake
Michigan*

OMC

WATER
WORKS

BREAKWATER

*Waukegan
Harbor*

Base Map from July 20 1939 Aerial Photograph

N

0   500   1000

Scale in Feet

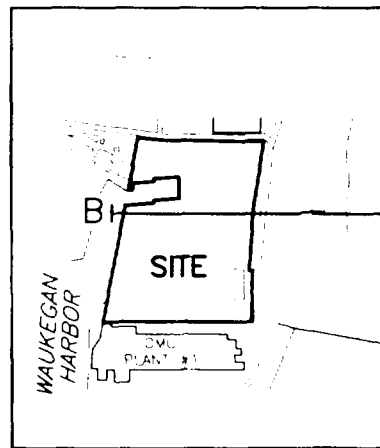|	
————————	1939 Shoreline
— ··— ··—	1954 Shoreline
——— ———	1959 Shoreline
- - - - - - -	1961 Shoreline
— — — —	1967 Shoreline
—— —— ——	1974 Shoreline
——— ··—	1981 Shoreline
————————	1988 Shoreline

Figure 2-A-2

WAUKEGAN HARBOR SHORELINE
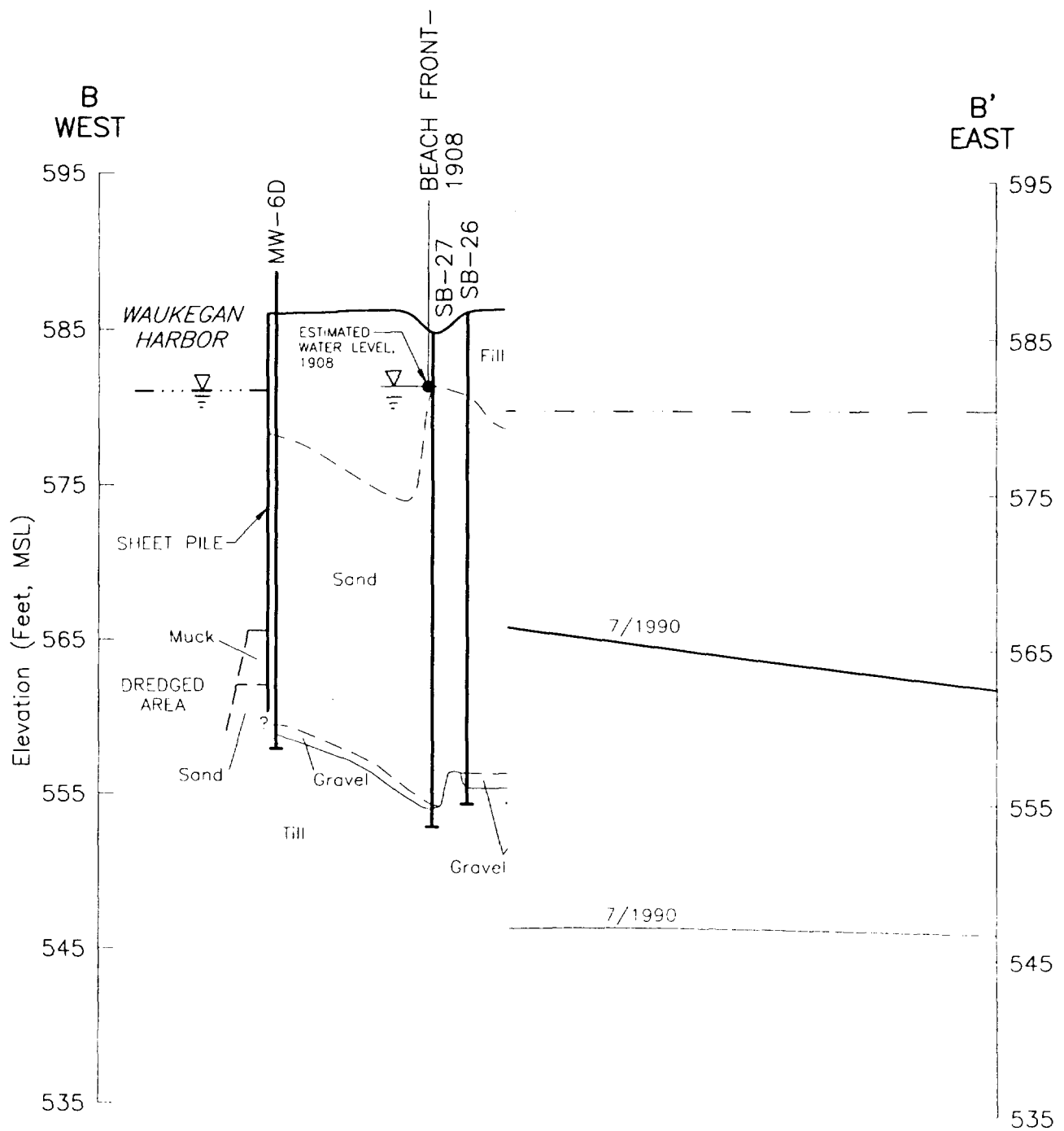
Figure 2-A-3
GEOLOGIC CROSS SECTION B-B'
ENERLIZED SCHEMATIC BASED ON RI REPORT
CROSS SECTION B-B')
SITE AND CROS'aukegan Manufactured Gas and Coke Plant
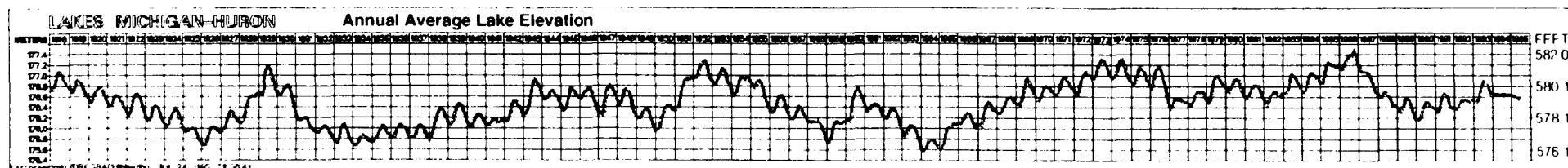
International Great Lakes Datum 1985
Source. Michigan-Huron Hydrograph Home Page, USACE Detroit GLHHB

Figure 2-A-4

LAKE MICHIGAN WATER LEVELS,
1918-1996

Figure 2-A-5
CONCEPTUAL ILLUSTRATION:
GROUNDWATER DISCHARGE AND
SHORELINE POSITION THROUGH TIME
Waukegan Manufactured Gas & Coke Plant Site
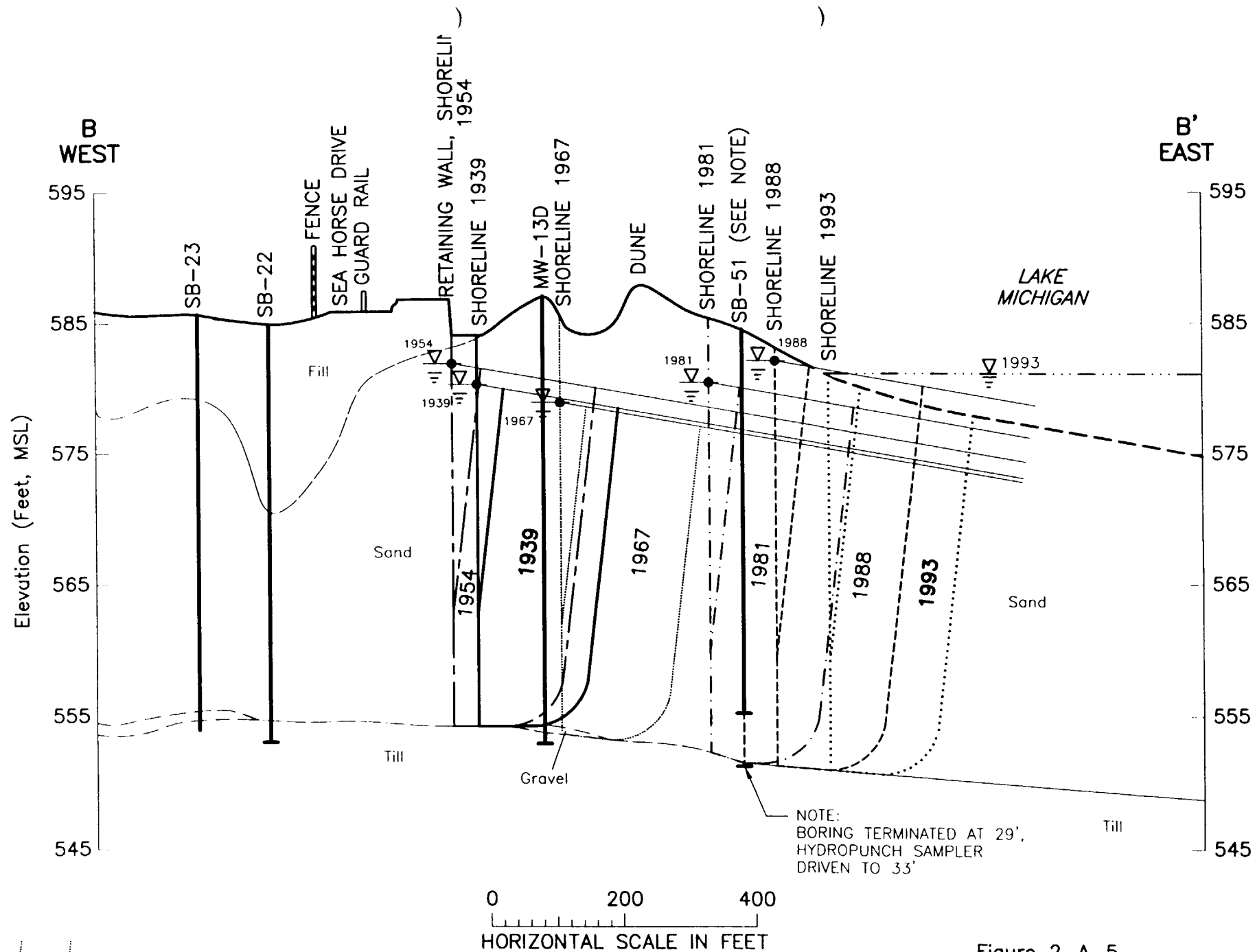
Groundwater Discharge Zone for Date Shown for
Groundwater in the Deep Portion of the Sand Aquifer

THE DUNES

INTRODUCTION

Illinois Beach State Park is a showcase for the last remaining area of beach-ridge/swale development in Illinois. The dunes are an area where beach ridges along the shore shore line of Lake Michigan have been sculptured and reshaped by the forces of wind. These beautiful low dunes contain a diversity of plant and animal life, climatic conditions, and geological features unique in Illinois.

The dunes occupy a long narrow strip of land along the shore of Lake Michigan from Waukegan on the south to Kenosha, Wisconsin, on the north. This long, narrow strip was known as the Waukegan Moorlands, the Waukegan Flats, or the Dunesland, long before it became Illinois Beach State Park.

The dunes provide the opportunity to experience a kaleidoscope of sounds, smells, and sights. They are a reservoir of knowledge about plant succession and dune ecology can be obtained. We have a responsibility to protect and preserve this natural legacy for the enjoyment and wise use by our present and future generations.

HISTORY

It wasn't until 1948 that the state acquired the first land of what is now Illinois Beach State Park. In 1950 the Illinois Dunesland Preservation Society was formed, its goals being the preservation and protection of the natural qualities of the beach-ridges, swales, and dunes. At this time the dunesland area was being threatened with further development by man. Through the efforts of the Dunesland Preservation Society, protective laws were passed. In 1964 the dunesland was dedicated, becoming the first nature preserve in Illinois!

GEOLOGIC SETTING

As recently as 12,000 years ago, solid glacial ice occupied the area that is now Lake Michigan. The Wisconsinan Glacier, the most recent glacier to enter Illinois, scoured out Lake Michigan and left behind material that has been reworked into the beach ridges and dunes of Illinois Beach State Park. This parent material, known as glacial drift, contains a large array of boulders, cobbies, pebbles, sands, silts, and clays.
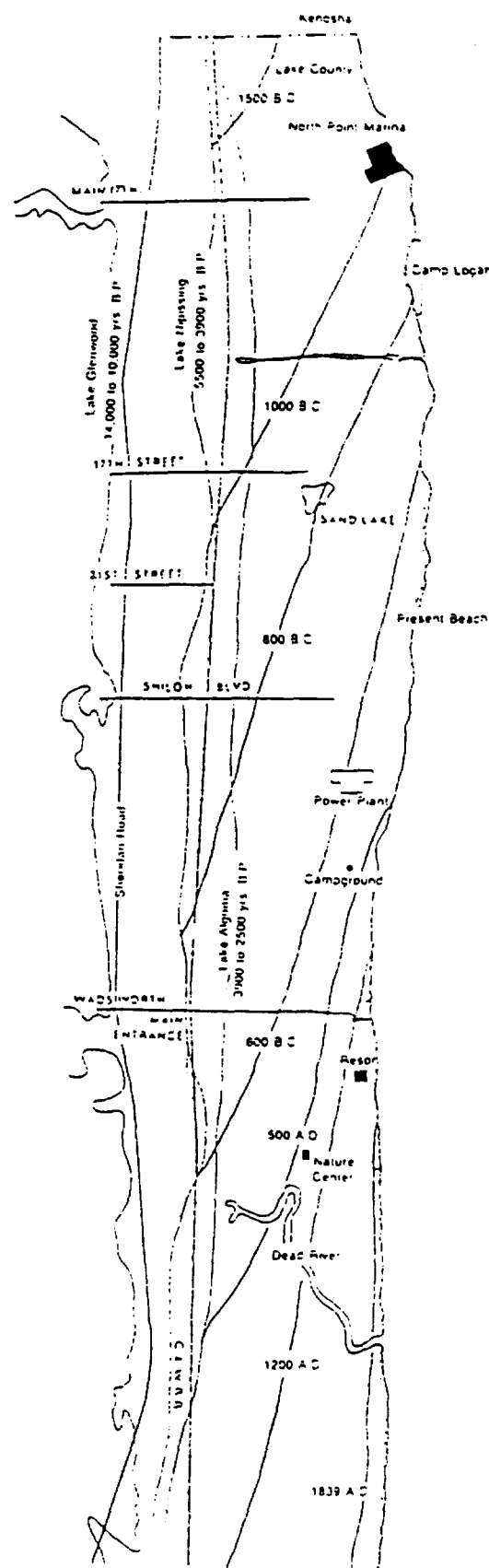
Map of the beach ridge and dune plains of Illinois Beach showing the older shoreline positions along the bluff.

As the glacial ice melted, the vast amount of water released created a lake with a water level more than 50 feet higher than the present level of the lake. This ancient lake, called Lake Chicago by geologists, inundated nearly all of the area where the City of Chicago now lies, as well as the entirety of Illinois Beach State Park.

When the glacier receded further north, which opened new outlets and ended the inflow of meltwater, the lake level fell to a position at least 80 feet below its present level. However, the northern outlets began to rise, once the enormous weight of the ice was removed, and water level gradually rebounded to a position about 25 feet above its present elevation, an episode of high water called the Nipissing phase. Following the Nipissing phase, the water gradually fell and has fluctuated within several feet of its present level throughout historic time. Beach terraces from ancient lake levels are preserved west of the Chicago and Northwestern Railroad tracks.

The beach ridges and dunes preserved in Illinois Beach State Park began to form approximately 3,000 years ago, a very young age by geologic standards. The beach ridges in the northwestern part of the park were the first ones to form. Successive beach ridges have been added to the south, while the lakeward ends of beach ridges to the north have been eroded away. The course of the old ridges somewhat resembles the shape of the present lakeshore and indicates positions of the shore during prehistoric time.

This process, still going on, is caused by the intense energy of waves and currents. Although dominant winds come from the west, the longest across the lake is to the northeast and winds from this direction have the greatest distance in which to gather waves. Waves from this direction are therefore much stronger than waves from other directions and gradually push sand particles toward the south. The net southerly movement sand at the shore can amount to dozens of feet in a single storm and in a year can be hundreds of feet.

DUNE FORMATION

Winds, blowing shoreward at speeds of 8 to 25 miles per hour, begin to move sand grains. These sand grains skip and bounce as they move, a process called saltation. As they move barely a foot or two off the gound, they may meet a slight obstruction, such as a clump of grass. The obstruction deflects the wind and allows any grains to crop. Thus a slight mound is created.

Sand movement through the process known as saltation.
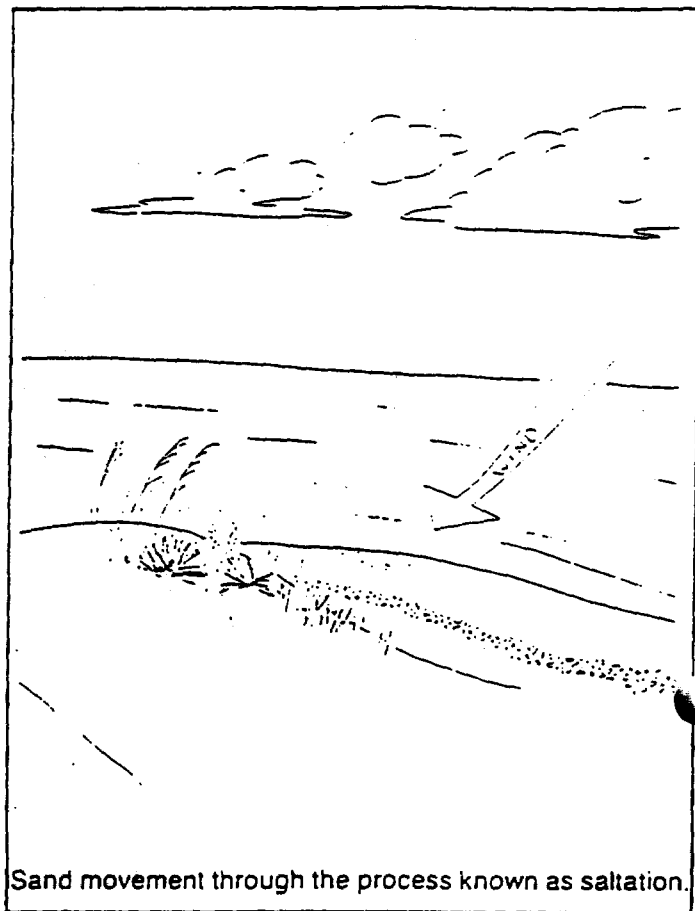
Only the small grains that make up sand can be moved by this method. By looking at the sand of the dunes and the sand of the beach and beach ridges one can see a marked difference. Beach sand, moved by the water includes not only coarse sand but also small rocks and stones. Dune sand grains are uniformly small and very smooth to the touch.

The wind pushes sand grains up the windward side of the dune crest, and the sand grains eventually roll down the steep backslope. This causes the dune to grow in downwind direction. A dune's continued growth depends upon wind, a source of sand, and presence or absence of vegetation. Because dune plants act as barriers to sand movement and hold migrating sand, they play a critical role in the formation and stabilization of dunes.

The dominant wind on Lake Michigan is from the west/southwest. This wind blows most of the dune sand lakeward on the west shore of Lake Michigan so dunes are small. On the east side of the lake, the prevailing winds blow the sand landward froming the large dunes of the Michigan and Indiana shore.

White Tailed Deer

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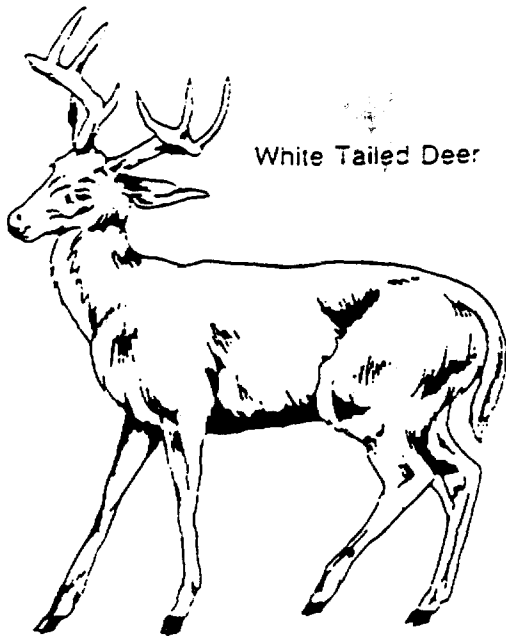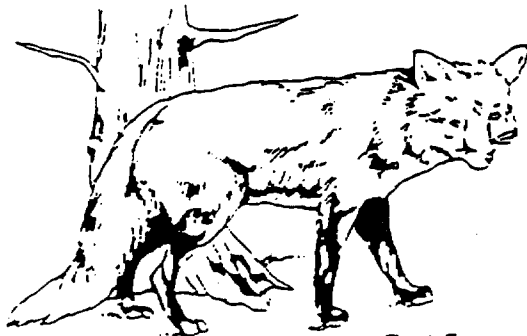
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Great Horned Owl

Red Fox

Illinois

Illinois
Department of
Conservation

SUCCESSION OF THE DUNES

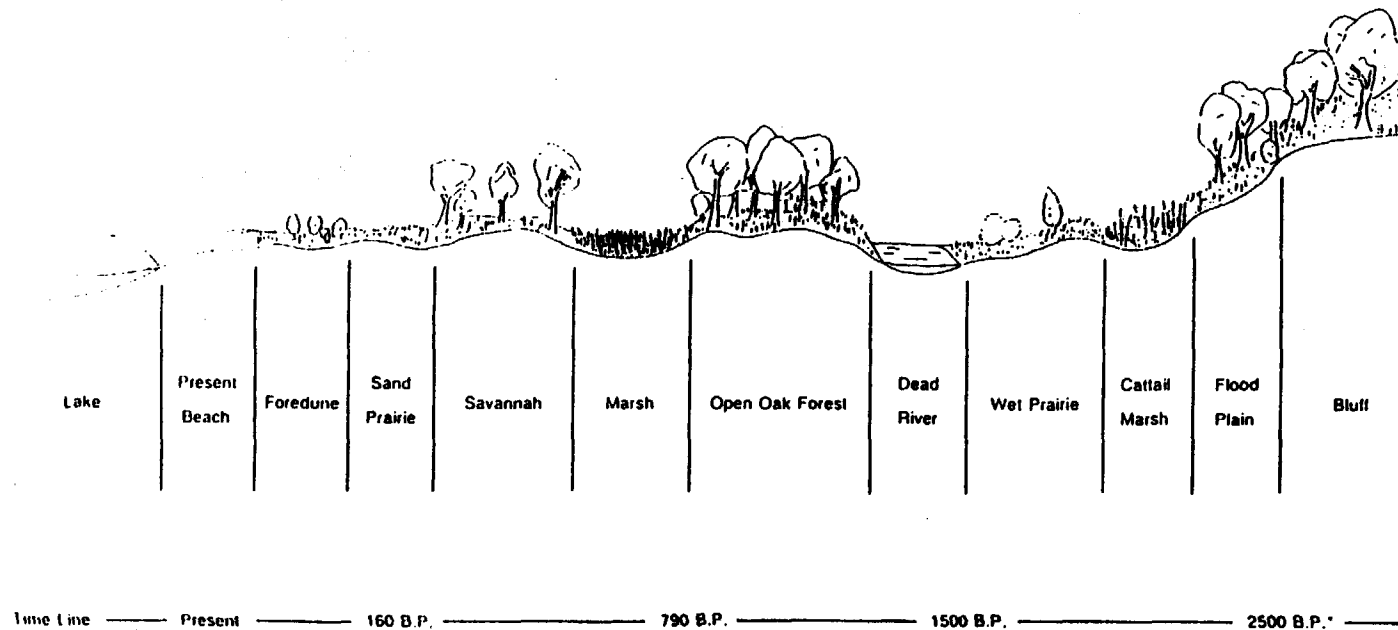| Lake | Present Beach | Foredune | Sand Prairie | Savannah | Marsh | Open Oak Forest | Dead River | Wet Prairie | Cattail Marsh | Flood Plain | Bluff |

Time Line ——— Present ——— 160 B.P. ——————— 790 B.P. ——————— 1500 B.P. ——————— 2500 B.P.* ———

Diagram showing plant succession from the beach to

the bluff on an east-west line running just south of the

Nature Center.

*B.P. = Before Present

Time line shows age of the old beach ridges.

Further to the west, beyond the rear dunes, is a community of oak trees which further help to stabilize the dunes. Black Oak and Choke Cherry are the characteristic plants, but there are many others: New Jersey Tea, Poison Ivy, Wild Grape, and several grasses, among them the native June Grass and Weedy, non-native Canada and Kentucky Bluegrass. Numerous showy flowers are found in the openings in the oak woods. Coreopsis, Lupine, Butterfly Weed, Western Sunflower, Showy Goldenrod Sky-blue and Heath Asters are here in profusion. More animals will be seen and heard: chipmunks, ground squirrels, gray squirrels, blue jays, towhees, and several kinds of sparrows, to mention only a few.

Still farther to the west, the oaks stop rather abruptly, and the prairie begins. Standing on a small dune west of the oaks and looking westward, we see the prairie divided into north-south strips, dry sandy prairie alternating with wet marshy prairie or sloughs. Dead River flows nearby. Here in the prairie is found the greatest variety of flowering plants. From May to October the color of the prairie changes almost weekly as different flowers start their blooming season. Characteristic of the dry sandy prairie are Sandwort, Spiderwort, Prairie Phlox, Black-Eyed Susan, Yellow Coneflower, Lead Plant, Purple and White Prairie Clovers, and Rough Blazing Star. Characteristic of the moist prairie are Grass Pink Orchid, Marsh Phlox, Shooting Star, Marsh Blazing Star, Boneset, Swamp Milkweed, Fringed Gentian, Sawtoothed Sunflower, and Sneezeweed.

This prairie represents a mature or stable association, given the conditions that exist now — the frequent fires, the present drainage system and the interference of man. If these factors should change, a deciduous forest might develop on the sandy ridges.

The Illinois Beach State Park Dunesland is an extraordinarily interesting and challenging region. Its complexity is reflected in the geology, the great variety of plants, the ecological succession and nature's uncertain future.

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Appendix 2-B

Groundwater Flow Modeling

Appendix 2-B

Groundwater Flow Modeling

List of Tables

List of Figures

Appendix 2-B
Groundwater Flow Modeling

As part of the Remedial Investigation (RI), a SLAEM (Single Layer Analytic Element Model) groundwater model of the site was developed to provide the following: (1) a tool for integrating and evaluating independent estimates of hydraulic parameters such as hydraulic conductivity and aquifer recharge; and (2) a basis for future evaluations of the effects of potential remediation scenarios on groundwater flow patterns and discharges. The model was also developed to supplement the extensive amount of measured site data for evaluating volumetric discharges of groundwater to Lake Michigan and Waukegan Harbor. The development and calibration of this groundwater flow model were discussed in detail in Appendix 5-C of the RI Report.

Subsequent to the RI Report, a more detailed review of the site water balance and the interaction between the beach and groundwater was conducted. The groundwater model was consequently refined and a separate two-dimensional SLAEM model was developed to simulate groundwater discharge to the lake. The refinements to the existing model and the development of the discharge model are summarized in this appendix.

Model Refinements

The groundwater monitoring (Appendix 5-A of the RI Report) indicate that the horizontal hydraulic gradient steepens between the eastern-most monitoring wells and the lake. The data also suggest a seasonal change in the configuration of the groundwater high in the center of the peninsula. These variations are attributed to locational and seasonal variation in infiltration. The existing model was refined to more accurately reflect these variations.

Higher Beach Infiltration

The steepening of the horizontal hydraulic gradient towards the lake is explained by higher infiltration at the beach than over the rest of the peninsula. A number of physical factors point to the likelihood of higher infiltration at the beach, such as: wave action, lake spray, permeable nature of beach and dune sands, sparse vegetation in the dunes area (resulting in decreased evapotranspiration), numerous depressions in which runoff accumulates, and high humidity and cool temperatures adjacent to the lake. Higher infiltration at the beach is also consistent with

published information about similar dunes areas, where infiltration rates in excess of 80 percent of the annual precipitation are reported (Frank, 1970).

To simulate higher infiltration at the beach, a higher recharge rate (referred to as the Areal Element Module in the SLAEM model) was applied along the beach. The distribution of infiltration is shown on Figure 2-B-1. As will be discussed below, the annual average model calibration was achieved at a site-wide annual infiltration rate of 11.5 inches and a beach average annual infiltration rate of 33.8 inches—an infiltration rate approximately equal to the annual average precipitation.

Seasonal Variations

The groundwater flow model was calibrated to average observed groundwater conditions in each of three seasonal trimesters. The model elements of each trimester and the annual average of all trimesters are summarized in Table 2-B-1. This table also lists the elements of the previous RI model for comparison.

For each trimester model, measured water level elevations were used to specify the heads at the head-specified elements representing Lake Michigan and Waukegan Harbor. When lake levels from RI monitoring points were not available due to frozen conditions, published lake levels were used. Site and beach infiltration rates were then adjusted until modeled water level elevations matched the observed elevations to within ± 0.2 feet. Adjusting the site-wide infiltration rate brought the predicted water level elevations into the same proximity as measured elevations, while adjusting the beach infiltration reduced the scatter in the calibration. Predicted heads and calibration results for each trimester and for the annual average are shown on Figures 2-B-2 through 2-B-9.

For the March through June calibration (Figures 2-B-2 and 2-B-3), there were only two measuring points at which the difference between predicted and observed elevations were greater than 0.2 feet. One of the locations, W-2A, is on OMC Plant No. 2 property, which is located far from the site and is not of material significance in judging the adequacy of the calibration for the site. The other location at which the difference between predicted and observed elevations was greater than 0.2 feet, MW-7S, is located on site. The measured elevation at MW-7S is assumed to be anomalous because of the good fit at the rest of the on-site locations. For the July through October calibration (Figures 2-B-4 and 2-B-5), all predicted elevations were within 0.2 feet of observed values. The November through February period represents a transition period from the end of the infiltration

season in November to virtually no infiltration in January and February. For the November through February calibration (Figures 2-B-6 and 2-B-7), there were two measuring points with a difference between predicted and observed elevations greater than 0.2 feet. One of these locations, MW-13S, lies between two other locations with very good calibration results (MW-12S and MW-14S); therefore, little weight is given to this outlier result. The second location, well W-12, lies on OMC Plant No. 2 property and is, therefore, not of material significance in judging the adequacy of the calibration for the site.

Figures 2-B-8 and 2-B-9 illustrate the predicted elevations and calibration for the annual average of infiltration conditions. Figure 2-B-10 illustrates the predicted groundwater divides on the peninsula and the segments used to calculate groundwater discharge rates to surface water. Figure 2-B-11 illustrates the average discharge rate for each segment.

The model refinements presented here have significantly improved the representativeness of the site groundwater flow model. The model in the RI was calibrated to within ± 0.5 feet of water elevations, only covering September to February data. The refined model, on the other hand, achieves a calibration of ± 0.2 feet for all seasonal data.

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Table 2-B-1

Summary of SLAEM Input Data for Calibration

	Original Calibration	Refined Annual Calibration	Mar.–Jun. Calibration	Jul.–Oct. Calibration	Nov.–Feb. Calibration
Aquifer Module					
Base Elevation of Aquifer (feet, MSL)	557	557	557	557	557
Thickness of Aquifer (feet)	33	33	33	33	33
Hydraulic Conductivity of Aquifer (feet/day)	31	31	31	31	31
Porosity of Aquifer (ft^3/ft^3)	0.38	0.38	0.38	0.38	0.38
Arel Element Module					
Global Infiltration Rate (feet/day)	0.00245	0.00262	0.00343	0.00282	0.00160
Beach Infiltration Rate (feet/day)	—	0.00771	0.00882	0.00882	0.00548
Linesink Module (constant-strength)					
Water Elevation of Lake Michigan (feet, MSL)	581	581.03	580.75	581.19	581.15
Water Elevation of Ponding Area (East of Storm Sewer Outlet) (feet, MSL)	582.49	582.45	582.28	582.60	582.47
Linesink Module (linear-strength)					
Water Elevations of North Ditch (feet, MSL)	582.84 to 581	582.68 to 581.03	582.54 to 580.75	582.68 to 581.19	582.83 to 581.15
Water Elevations of Surface Water Drainage (Northeast of Site) (feet, MSL)	582.49 to 581	582.45 to 581.03	582.28 to 580.75	582.60 to 581.19	582.47 to 581.15
Curvilinear Module (head-specified)					
Water Elevation of Waukegan Harbor (feet, MSL)	581	581.03	580.75	581.19	581.15
Curvilinear Module (leaky)					
Resistance Values of Slurry Wall, Eastern End of Slip No. 4 (days)	7,100	7,100	7,100	7,100	7,100
Thickness of Slurry Wall, Eastern End of Slip No. 4 (feet)	2	2	2	2	2
Resistance Values of Retaining Walls Along Harbor (days)	2 to 20	2 to 20	2 to 20	2 to 20	2 to 20
Estimated Thickness of Retaining Walls Along Harbor (foot)	1	1	1	1	1

A

B

H

F

BEACH
INFILTRATION

C

D

NO
INFILTRATION

D'

SITE-WIDE
INFILTRATION

E'

E

SCALE IN FEET
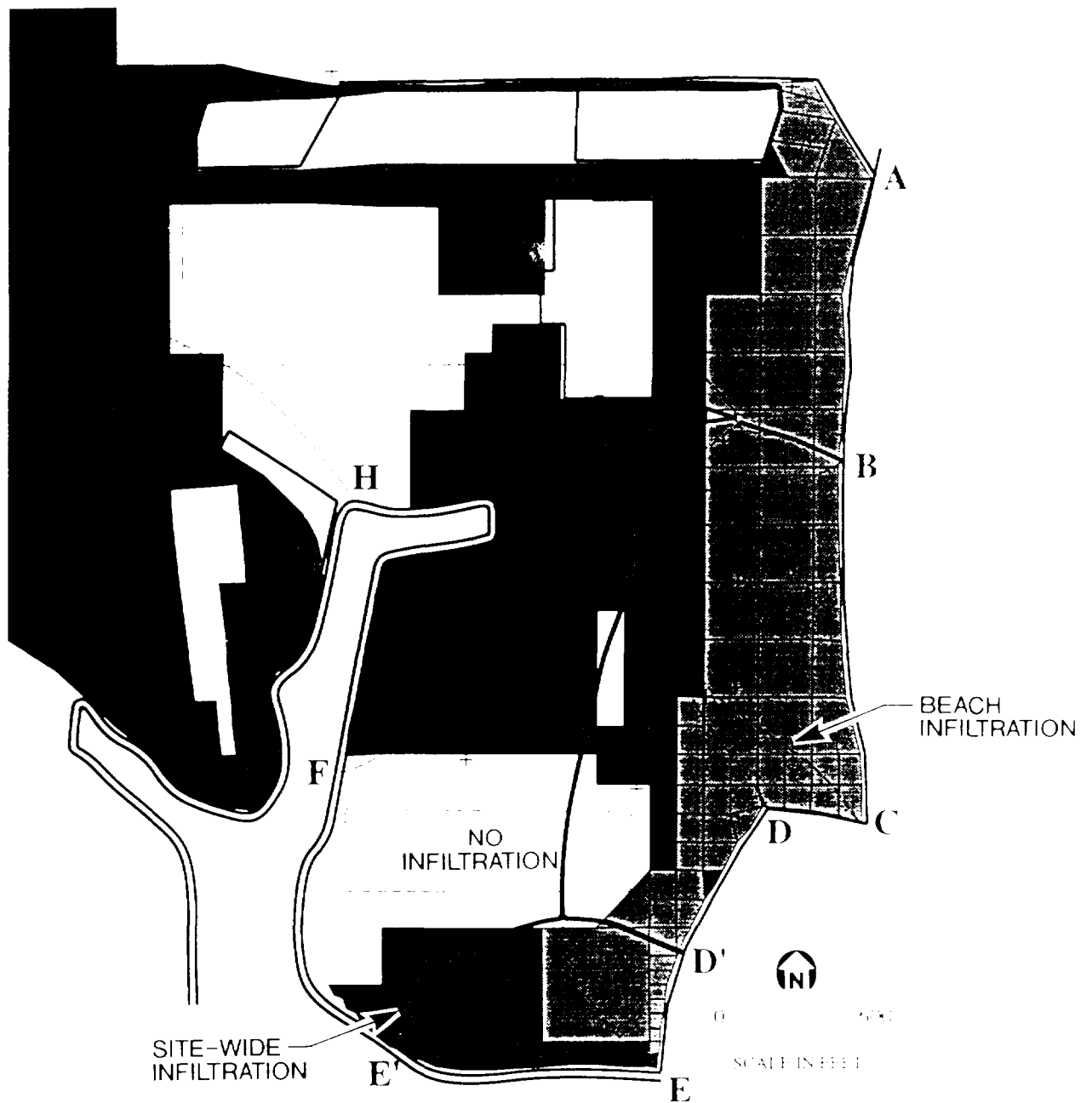
Figure 2 B 1

SITE LAYOUT AND LAYOUT OF
INFILTRATION ZONES
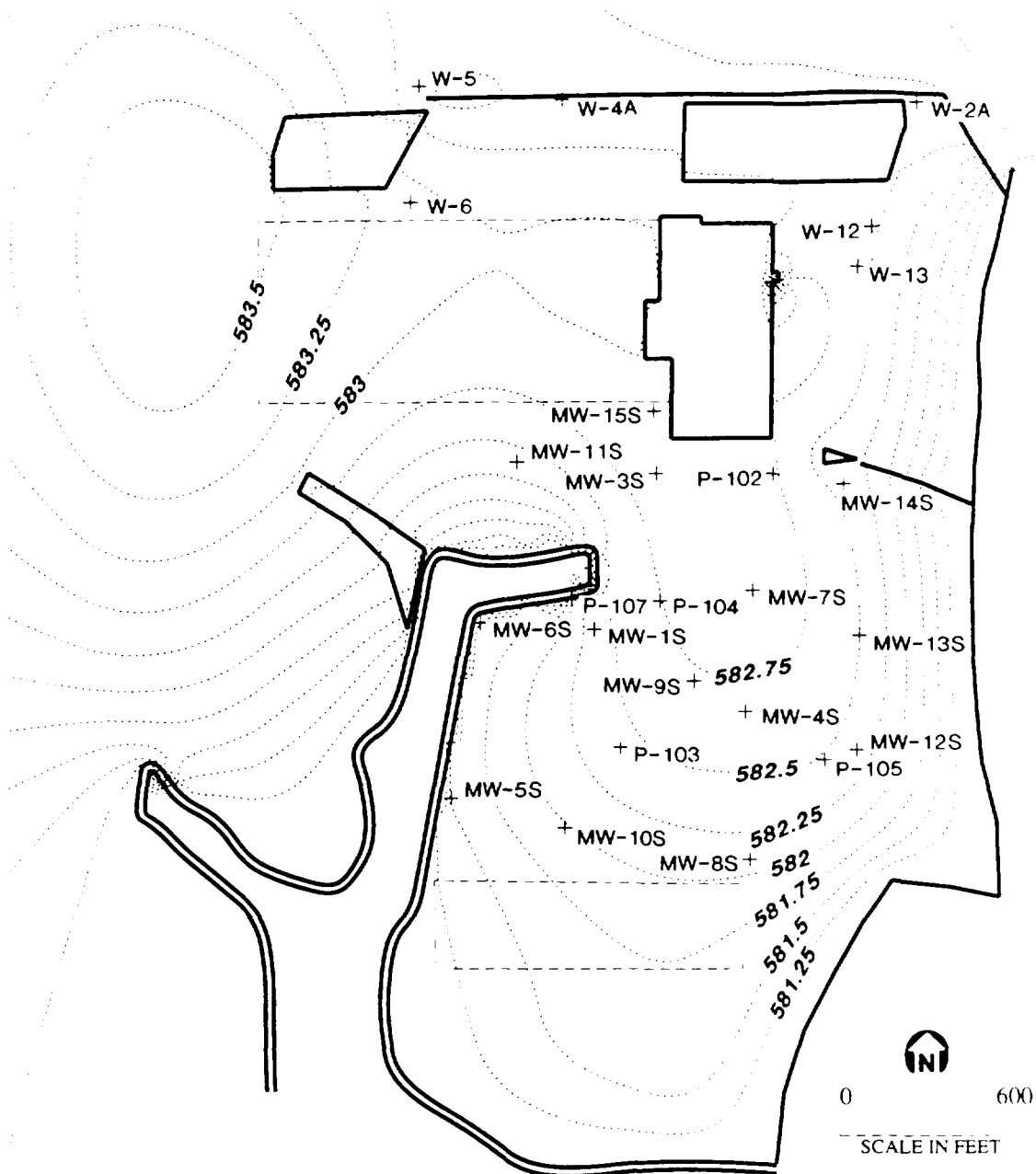
Figure 2-B-2

CONTOURS OF SIMULATED
PIEZOMETRIC HEAD
March through June

Seasonal Calibration (March-June)
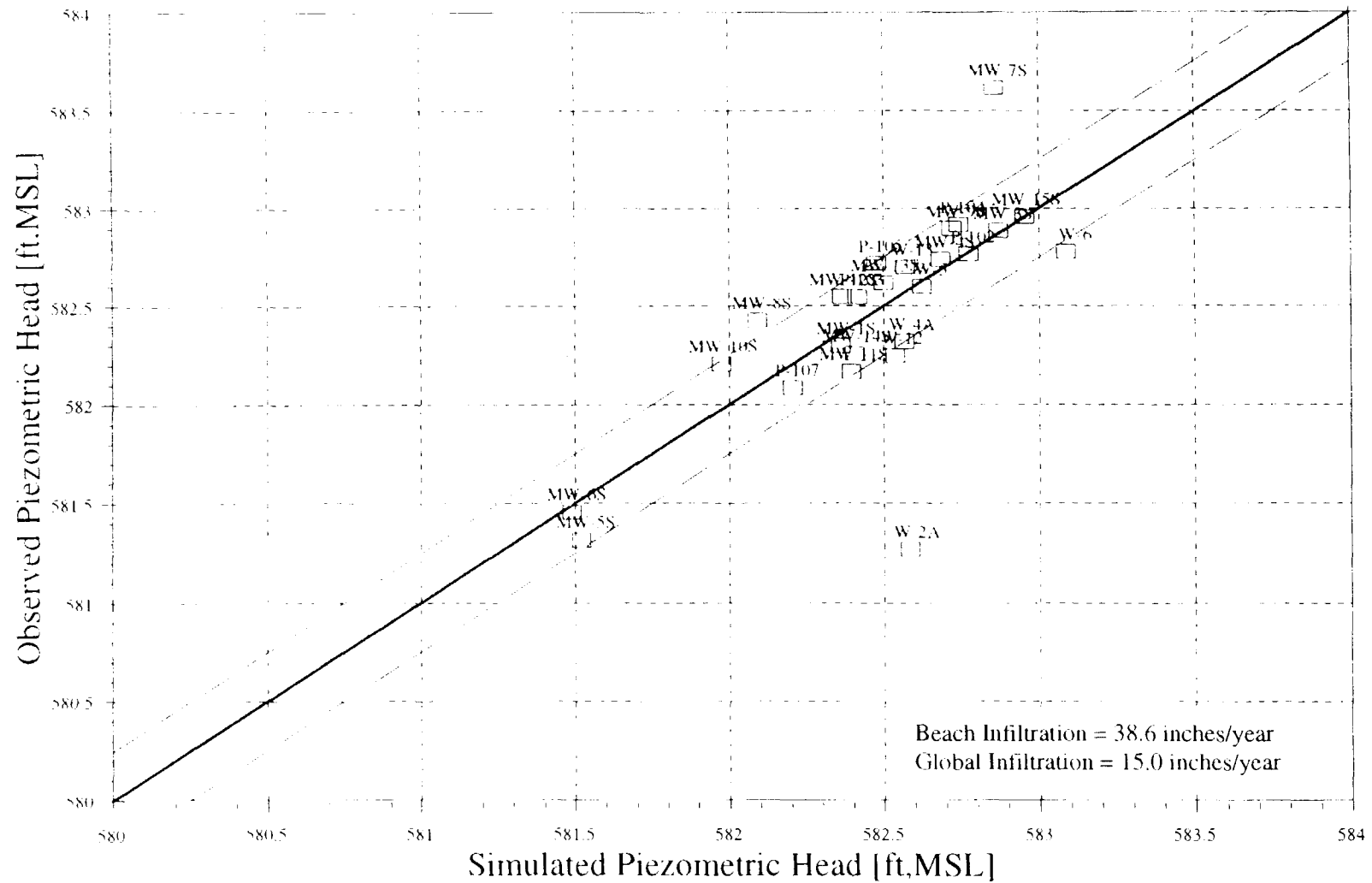
Figure 2-B-3

SEASONAL CALIBRATION
March through June
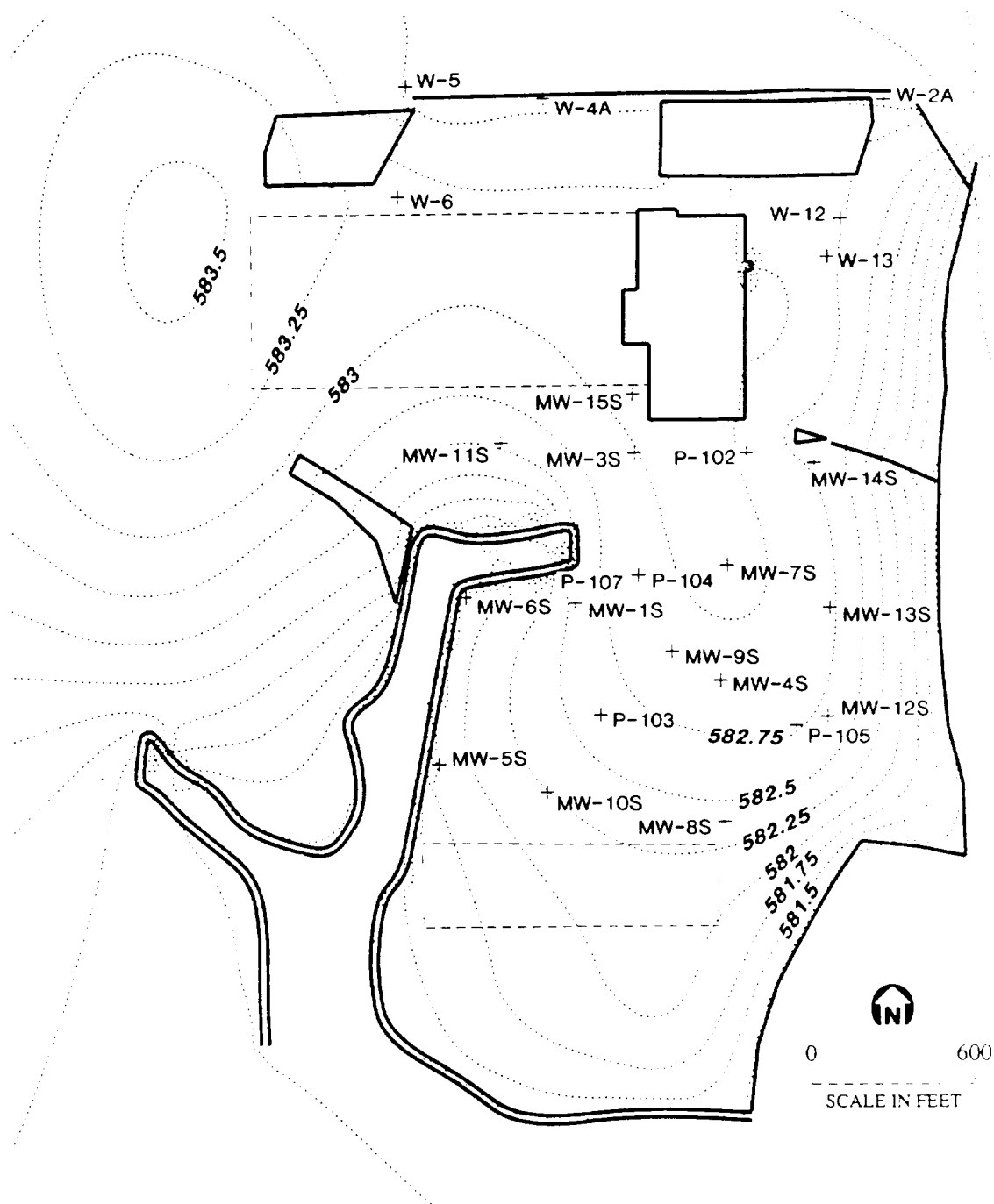
Figure 2-B-4

CONTOURS OF SIMULATED
PIEZOMETRIC HEAD
July through October
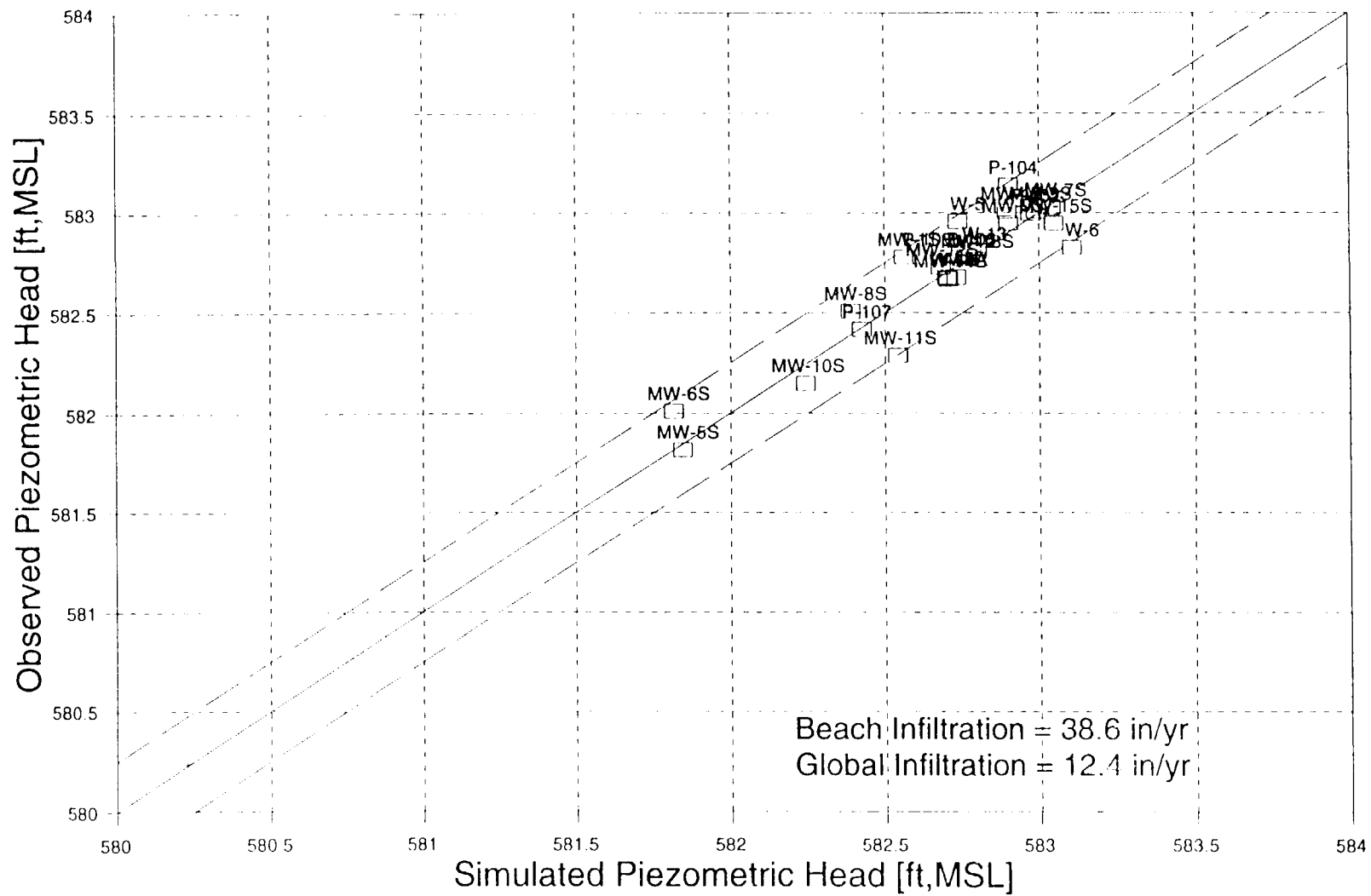
Figure 2-B-5

SEASONAL CALIBRATION
July through October

W-5 +

W-4A

+ W-2A

+ W-6

W-12 +

582.75

+ W-13

MW-15S +

MW-11S +

MW-3S +

P-102 +

+
MW-14S

582.5

P-107 + P-104 +

+ MW-7S

+ MW-6S

+ MW-1S

MW-13S +

+ MW-9S

MW-4S +

582.25

+ P-103

P-105 +

+ MW-12S

+ MW-5S

582

+ MW-10S

MW-8S +

581.75

581.5

581.25

0   600

SCALE IN FEET
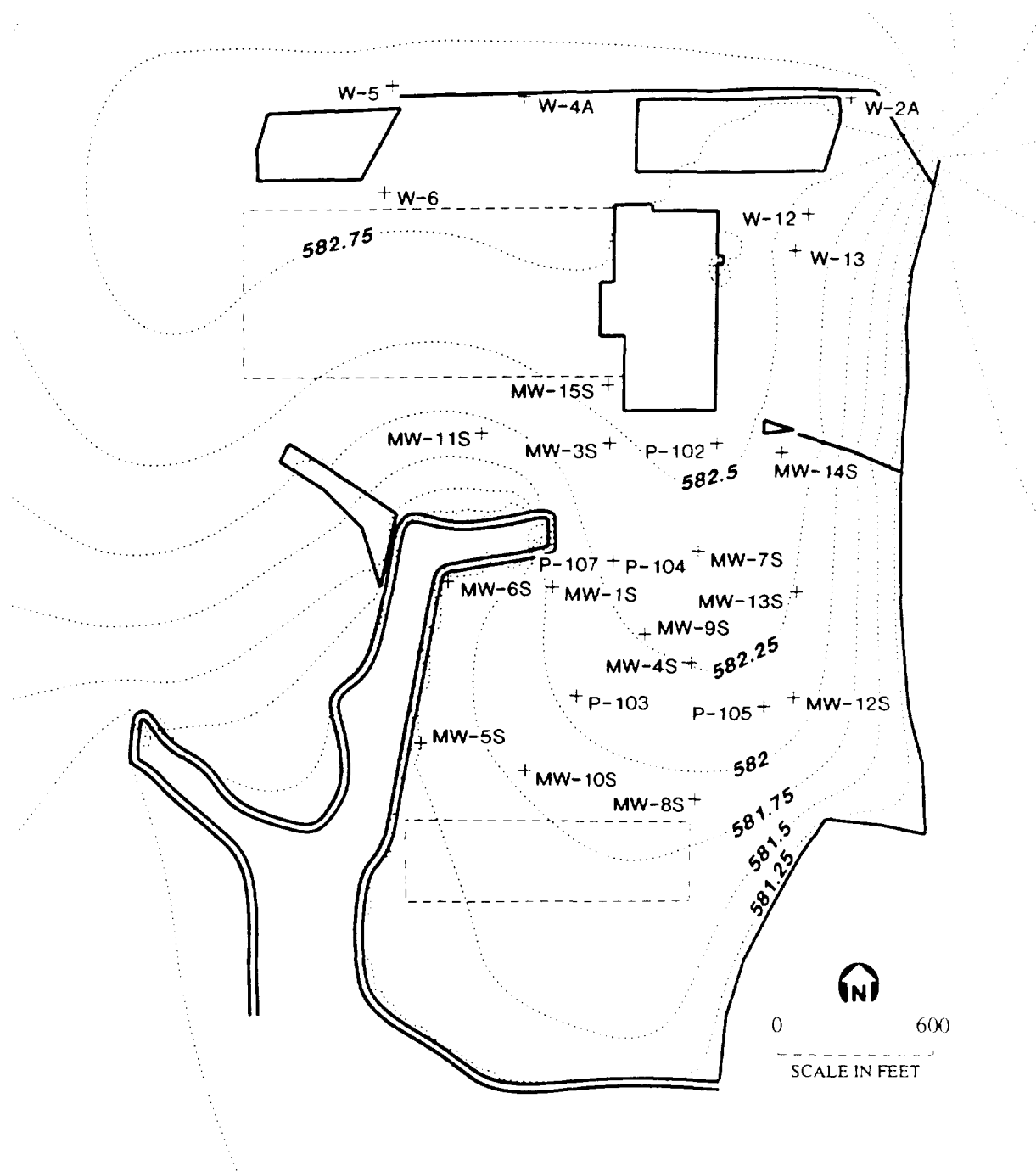
Figure 2-B-6

CONTOURS OF SIMULATED
PIEZOMETRIC HEAD
November through February

Figure 2-B-7

SEASONAL CALIBRATION
November through February

+ W-5

W-4A

+ W-2A

+ W-6

W-12 +

+ W-13

583.25

583

582.75

MW-15S +

MW-11S +

MW-3S +

P-102 +

+ MW-14S

P-107 + P-104 + MW-7S

MW-6S + + MW-1S

+ MW-13S

+ MW-9S

+ MW-4S

P-103 +

582.5 + + MW-12S

P-105

582.25

+ MW-5S

+ MW-10S

MW-8S +

582

581.75

581.5

581.25

0   600

SCALE IN FEET

Figure 2-B-8

CONTOURS OF SIMULATED
PIEZOMETRIC HEAD
ANNUAL AVERAGE CALIBRATION

Figure 2-B-9

ANNUAL AVERAGE CALIBRATION

W-5 +
+ W-4A
+ W-2A
L

+ W-6

+ W-12
+ W-13

MW-15S +

MW-11S +
MW-3S +
P-102 +
MW-14S +
K

A B   C

D
E
P-107 + P-104
+ MW-7S
+ MW-6S + MW-1S
+ MW-13S

MW-9S +

+ MW-4S
P-103 +
P-105 + + MW-12S

+ MW-5S

F
+ MW-10S
+ MW-8S
I
J

H

G

0   600

SCALE IN FEET

Figure 2-B-10

PREDICTED GROUNDWATER DIVIDES
AND DISCHARGE SEGMENTS

Discharge Segment	Total Groundwater Discharge (gpm)
AB	2 7
BC	8 6
CD	1 8
DE	5 8
EF	4 6
FG	4 3
GH	11 5
HI	12 1
IJ	4 2
JK	22 5
Total	78.09

Figure 2-B-11

ANNUAL AVERAGE
DISCHARGE RATES

Appendix 2-C

Effect of Peninsular Groundwater Hydraulics on Groundwater Flow and Chemical Distribution

Appendix 2-C

Effect of Peninsular Groundwater Hydraulics
on Groundwater Flow and Chemical Distribution

List of Figures

List of Figures (cont.)

Appendix 2-C

Effect of Peninsular Groundwater Hydraulics
on Groundwater Flow and Chemical Distribution

Introduction

Groundwater modeling was used to examine the hydraulic effects of beach accretion and changes in site conditions on general groundwater flow patterns beneath the peninsula. The purposes of these modeling efforts are:

1. to explain stratification of chemical concentrations in the aquifer

2. to help understand the effect of beach accretion and other major site changes such as the creation of Slip No. 4 in the northwestern portion of the site on:

    –   horizontal groundwater flow patterns beneath the peninsula

    –   vertical advective transport of chemicals over time.

Plan views showing groundwater flow conditions and groundwater flow path traces were generated for each of the site conditions simulated. Transects along flowpaths ending either at the lakeshore or at the harbor were generated and used to analyze the different behavior of vertical advective plume transport near a fixed boundary discharge area (i.e., harbor) and near a moving boundary discharge area (i.e., retreating lakeshore). For this purpose, flow modeling along vertical cross-sections were conducted, which differ from the site-wide (horizontal) groundwater flow models.

Simulations

A series of steady state models was set up to represent shoreline and harbor conditions that were prevailing in 1970 (with and without ponds), 1974, 1981, 1988 (with and without Slip No. 4), 1993 and 1997. For this purpose, the refined site-wide groundwater flow model was used; as presented in Appendix 2-B.

The locations of the shoreline were obtained from historical aerial photographs of the site. The model representing the 1970 groundwater flow conditions with ponds used a 1967 shoreline. The groundwater divide was assumed to coincide with the location of the ponds. Pond locations, assumed to be aqueous discharge zones, were obtained from historical aerial photographs of the site, as shown on Figure 2-C-1. The ponds were simulated as having a water level 5 feet above water table.

Simulated piezometric heads for the above-referenced steady state simulations are shown on Figures 2-C-2 through 2-C-5. Figure 2-C-2 indicates that the modeled infiltration at the groundwater divide was a driving force for site groundwater flow. In Figure 2-C-3 through 2-C-5, peninsula-wide infiltration is the primary driving force for groundwater flow. The modeling shows there was an eastward shift of the groundwater divide due to beach accretion. The presence of the slip created a further eastward shift in the groundwater divide, along with increased groundwater discharge to the harbor side of the peninsula.

Groundwater flow path traces passing through monitoring well MW-13D on the beach side, and through monitoring well MW-1D on the harbor side were generated by each of the simulations, as shown on Figures 2-C-6 and 2-C-7, respectively. On each of the traces, tickmarks representing the distance traveled in one year by groundwater are presented. The density of the tickmarks indicates a much slower groundwater velocity as water moves in the vicinity of the groundwater divide.

Transect Transport Models

The groundwater models were used to generate a series of cross-sectional transects along the flowpath traces. These flowpath traces are shown on Figure 2-C-6 and 2-C-7.

The transects were used to conceptually analyze the behavior of assumed plumes of chloride (a conservative tracer) and phenol (a retarded tracer), as they moved from the groundwater divide toward the lake and the harbor. The analysis considered only two transport mechanisms: advection and retardation. Dispersion and degradation were not taken into account.

The analysis assumed that the transport of chloride and phenol in the aquifer can be visualized through a series of snapshots of quasi-steady state conditions, simulated for the different dates. In reality, the groundwater conditions change gradually as the lake boundary moves and as conditions at the site vary. This simplified approach, however, provides insight on the general behavior of the site chemical plumes. Due to the absence of calibration data, the results are viewed as conceptual findings.

Method for Estimating Plume Locations

Site history indicates there may have been aqueous discharges at the site from completion of plant construction in 1928 until site grading after plant demolition in 1972, a period of 44 years. For the purposes of this analysis, the aquifer initial conditions were generated using 41 years of aqueous discharge loading to the groundwater. Since the purpose of this modeling and analysis is to provide a conceptual illustration of the significance of beach accretion and other physical changes at the peninsula on groundwater flow and plume migration, the small discrepancies between modeling assumptions and site history have not been rectified.

The initial (1970) chloride plume distribution along the beach side was estimated using the 1967 shoreline with ponds (Figure 2-C-2). The location of the chloride plume in 1970 was estimated by following each flowpath trace 41 tickmarks from the ponds (since each tickmark represents the distance traveled in one year by a conservative tracer such as chloride). The 1970 location of the chloride plume along the beach transect is depicted in Figure 2-C-8. The 1974 location of the chloride plume was derived with the 1967 shorelines, but without ponds (Figure 2-C-3). The front and the back of the 1970 plume were then moved along flowpath traces by 4 ticks (i.e., distance traveled between 1970 and 1974). The resulting location of the plume is shown in Figure 2-C-9. Similar procedures were used to delineate the 1981 and 1988 plume locations. The 1981 plume delineation used the 1981 flow model in order to depict the fast growth of the beach between 1974 and 1981.

The locations of the chloride plume in 1981 and 1988 are shown in Figures 2-C-10 and 2-C-11, respectively. The groundwater model with the 1988 shoreline and Slip No. 4 was used to generate the transect used to estimate the location of the plume in 1993 (Figure 2-C-12). The groundwater model with Slip No. 4 and the 1993 shoreline was used to estimate the location of the chloride plume model in 1997 (Figure 2-C-13). Figure 2-C-14 shows the superimposed simulated locations of the chloride plume in 1970, 1974, 1981, 1988, 1993, and 1997 on the beach side.

To estimate the locations of the chloride plume along the harbor side, only three groundwater flow models were used, as groundwater conditions on the harbor side remained relatively unchanged after plant demolition activities until Slip No. 4 was constructed.[1] The simulated locations of the chloride plume are depicted in Figures 2-C-15, 2-C-16, and 2-C-17, for 1970, 1988, and 1997, respectively. Figure 2-C-18 shows the superimposed simulated location of the chloride plume in 1970, 1988, and 1997 on the harbor side.

The locations of the phenol plume on the beach and harbor sides were derived using the same methodology and the same groundwater models described above, with a variation that takes into account the fact that phenol is retarded. A retardation factor of 3.6 for phenol was used for the upper two thirds of the aquifer, and a retardation factor of 6.3 was used for the bottom one third[2]. The phenol plume estimates in 1970, 1974, 1981, 1988, 1993, and 1997, for the beach transect are shown on Figure 2-C-19, and the estimates for 1970, 1988, and 1997 for the harbor transect are shown on Figure 2-C-20.

Chloride and Phenol Transport Analysis

Figure 2-C-8 showing the transect of the estimated plume location on the beach side prior to plant demolition illustrates that the water infiltrating at the groundwater divide dominated groundwater flow patterns at the site. The aqueous discharge at the groundwater divide created an initial vertical stratification, with the discharge water beneath the water that infiltrates from rainfall.

After the plant was demolished, the initial stratification was accentuated by the infiltration at the site. The infiltration flushed the top of the chloride plume out of the aquifer. The cumulative effect of this is illustrated in Figure 2-C-14.

The lake has a general effect of creating an upward movement of the plume toward the discharge zone beneath the lake. It should be noted that groundwater velocities along the flowpaths that

---

[1] The location of the chloride plume in 1970 along the harbor transect was derived from the results of the groundwater model with the 1967 shorelines and with simulated ponds. The location of the chloride plume in 1988 was derived from the results of the groundwater model with the 1967 shorelines without the simulated ponds. Finally, the location of the chloride plume in 1997 was derived from the results of the groundwater model with the 1988 shoreline and with Slip No. 4 simulated.

[2] These retardation factors were estimated from total organic carbon values and porosity measured in samples collected during the remedial investigation at different depth intervals. Using these two retardation factor values, each tickmark in the transects was assumed to represent a distance traveled during 3.6 years and 6.3 years, depending on whether the phenol particle is located with the upper two-thirds or the bottom one-third of the aquifer.

move upward to the lake bottom are much larger in the upper portion of the aquifer, and decrease considerably with depth (Figures 2-C-8 through 2-C-13). As the plume is reduced downward to the lower portion of the aquifer by infiltration, its discharge is slowed by that zone of low velocities. Because the beach and discharge zones are in motion, the longer it takes for groundwater to discharge, the more opportunity there is for mixing and attenuation of the plume prior to reaching the lake.

As the beach advanced, the portion of the plume that was initially moving upward toward the bottom of the lake was swept downward by the added infiltration at the newly exposed beach. This effect is more pronounced when the beach accretion rate is larger, i.e., between 1974 and 1981.

The same effects can be described for phenol (Figure 2-C-19), the major difference being the smaller distance traveled by phenol compared to that traveled by a conservative tracer such as chloride.

On the harbor side, there is no moving boundary. Thus, the only mechanism observed is that the chloride and phenol plumes are swept into the deep portion of the aquifer by infiltration (Figures 2-C-18 and 2-C-20).

On the lake side, the upward movement toward the lake bottom followed by the horizontal downward movement as the beach advanced has created a significant smearing of the plume in the upper portion of the plume. The added infiltration in the new portion of the beach has added dissolved oxygen and created conditions favorable for aerobic degradation. This has led to further reduction of biodegradable compounds.

The above modeling and analysis provides conceptual insights on the behavior of the contaminant plumes at the site. Actual plume migrations are more complex and vary in response to spatial and/or temporal changes in several parameters such as hydraulic conductivity, infiltration, total organic carbon content/retardation factor, beach movement, as well as degradation, dispersion, smearing and dilution.

Three general conclusions can be drawn from this analysis:

1. Groundwater hydraulics can explain the stratification of the site groundwater, with the plume lying in a relatively thin zone at the base of the aquifer—on both the lake and harbor sides of the site.

2. In the past, the groundwater plume discharged or passed through much of what is now the dunes area east of the site.

3. The movement of the beach has changed the groundwater flow patterns, enhancing the attenuation of the plume prior to its discharge to the surface water.

Groundwater Discharge to Lake Michigan

A separate, cross-section groundwater flow model was developed to determine the size of the discharge zone for groundwater discharge into Lake Michigan. This information was subsequently used to frame the near-shore zone issue for groundwater mixing with surface water (see Appendix 2-D).

The general nature of groundwater discharge to surface water bodies is well known. The discharge is greatest at shoreline and decreases exponentially with distance from the shoreline (McBride and Pfannkuch, 1972). The SLAEM computer program, which is based on the Analytic Element Method (Strack, 1989), was utilized to construct a two-dimensional vertical-plane representation of groundwater flux into the lake. The objective of the analysis was to characterize the size of the discharge zone into the lake for estimating groundwater to surface water mixing ratios. Due to the absence of calibration data, the results of this modeling effort are viewed as conceptual findings.

Model Assumptions

The following assumptions were incorporated into the SLAEM lake-discharge model:

- The aquifer was modeled as a single-layer system with a base elevation of 557 feet above mean sea level (MSL), an aquifer thickness of 24 feet at the shoreline, an hydraulic conductivity of 31 feet/day, and a porosity of 38 percent. These parameters are the same as or similar to those of the refined site-wide groundwater flow model (Table 2-B-1).

- The aquifer was modeled assuming steady-state groundwater flow conditions. This assumption does not address temporal variations in lake elevations and groundwater fluxes.

- Variations in aquifer thickness—from 24 feet at the shoreline to 0 feet at a large distance east of the shoreline—were included in the model to account for changes in aquifer thickness underlying Lake Michigan. Based on maps of lake depth from the Lake Michigan Mariners' Atlas (Gulf Publishing Co., 1988) and lake cross-sectional information in Shabica and Pranschke (1993), it is evident that the sand deposits that form Waukegan beach extend thousands of feet into Lake Michigan. The sand deposits gradually thin until the underlying glacial till is exposed. The model assumed that the aquifer thins linearly from the shoreline to the glacial till outcrop beneath the lake.

- The base of the aquifer was assumed to act as an aquitard. Based on estimates of negligible interaction between deep aquifers and the aquifer at the site, this assumption appears to be appropriate and consistent with the site-wide data.

- Groundwater flow paths from the site were assumed to be horizontal at the shoreline.

- The discharge flux rate to Lake Michigan, a total flux rate of 2.4 ft^2/day (vertical plane at a point along the shoreline), was obtained from the site-wide model. This total flux rate was evenly distributed along the entire thickness of the aquifer in the groundwater discharge model.

- The lake was assumed to be in direct connection with the aquifer. This connection is evident by the existence of sandy sediments characteristic of the aquifer out into the lake. The water elevation of Lake Michigan (581.1 feet MSL) establishes the boundary conditions at the top of the aquifer.

- A uniform vertical-to-horizontal anisotropy ratio of 1:4 in hydraulic conductivity of the aquifer was used. This anisotropy was the value obtained from field investigations involving pumping tests.

Model Results

Generalized flow patterns of groundwater under Lake Michigan for the lake-discharge model are shown in Figures 2-C-8 through 2-C-13. Groundwater flow paths generated from the model indicate discharge of deep aquifer water farthest from the lake shore while shallow aquifer water discharges close to shore. Each tick along the flow paths represents a travel time of one year For all practical purposes, the groundwater discharges within 250 feet of the shoreline.

1967
1974
1981
1988
1993
1997

MW-15
MW-11
MW-3
MW-14
MW-7
MW-6
MW-1
MW-13
MW-9
MW-4
MW-12
MW-5
MW-10
MW-8

N

0   600
Scale in feet
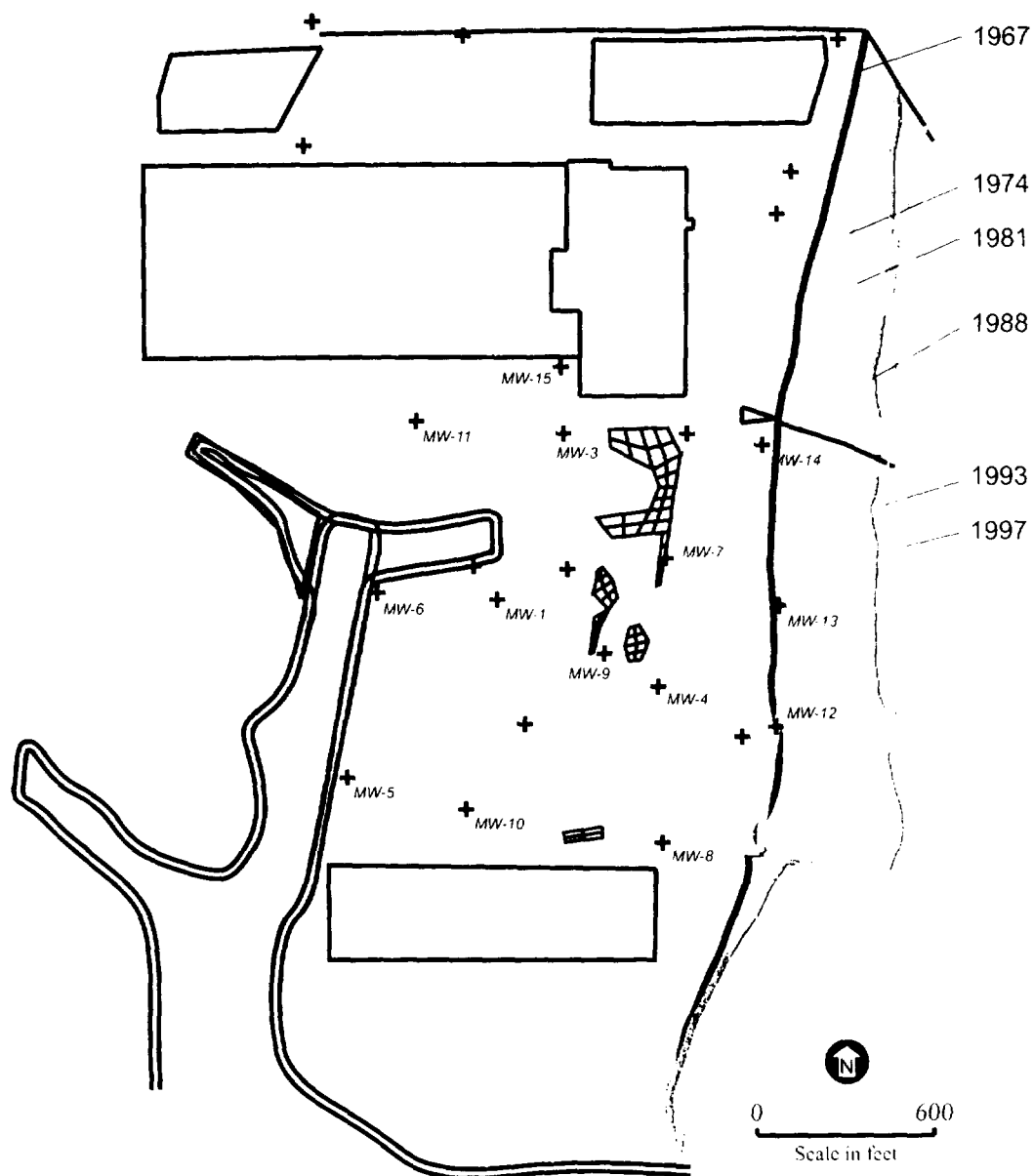
NOTE: Aqueous discharges ceased following plant demolition in 1972
Harbor configuration changed in 1991

Aqueous Discharge Zone

Figure 2-C-1

SUMMARY OF MODEL BOUNDARY CONDITIONS
REFLECTIVE OF SITE/HARBOR/LAKE CHANGES
BETWEEN 1967 AND 1997

MW-15

MW-11   MW-3

MW-14

MW-7

MW-6   MW-1   583.50   MW-13
                583.25
         MW-9
        583.00   582.75   MW-4
                  582.50   MW-12
                  582.25
MW-5   582.00
        MW-10
                  581.75   MW-8
                  581.50
                  581.25

0   600

Scale in feet
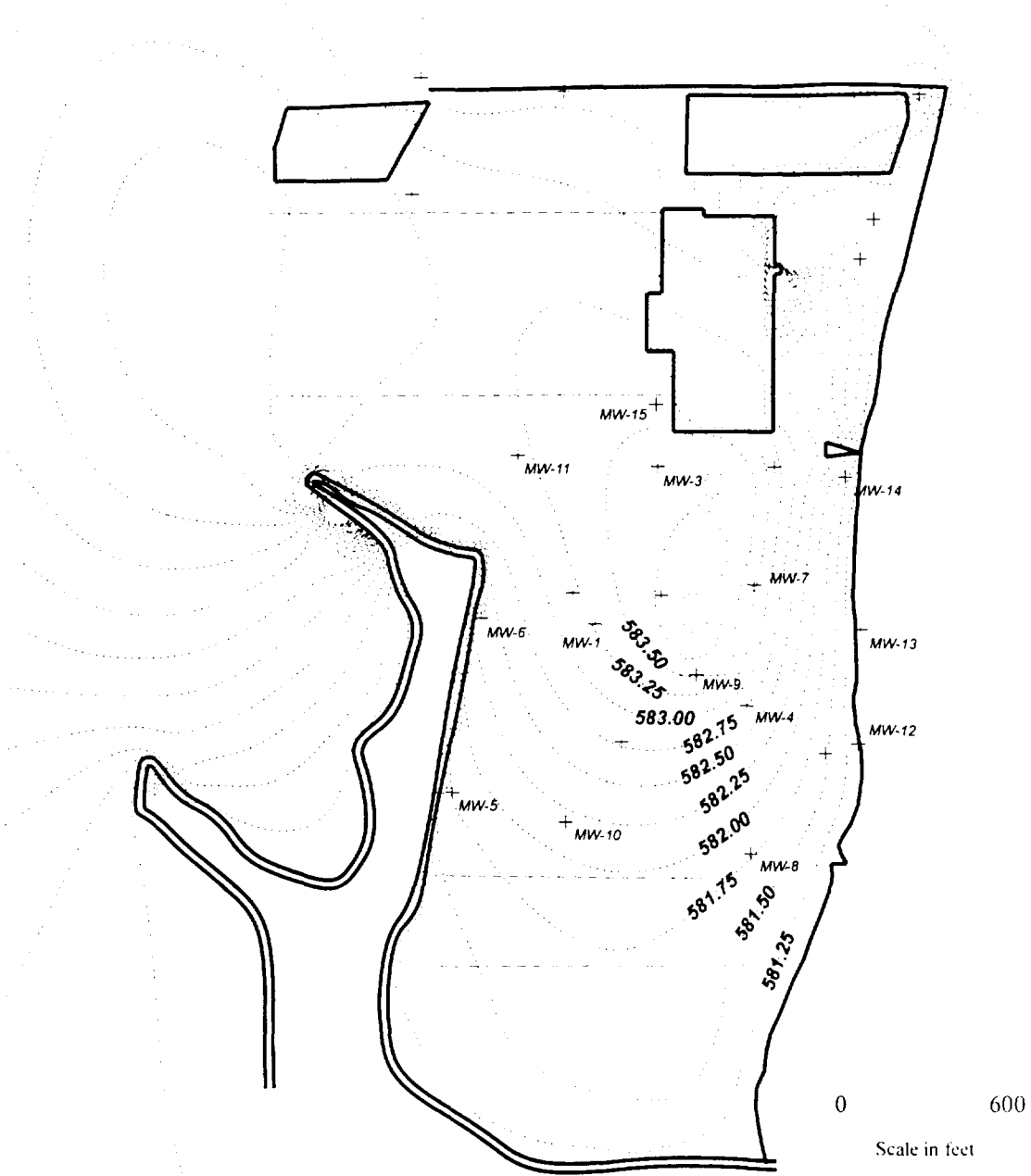
Figure 2-C-2

SIMULATED PIEZOMETRIC HEADS
1967 SHORELINE, WITH PONDS

582.75

MW-15

MW-11   MW-3

582.50

MW-7

582.25

MW-6   MW-1

MW-14

MW-13

MW-9

582.00   MW-4

MW-12

581.75

MW-5

581.50

MW-10

581.25   MW-8

0   600

Scale in feet
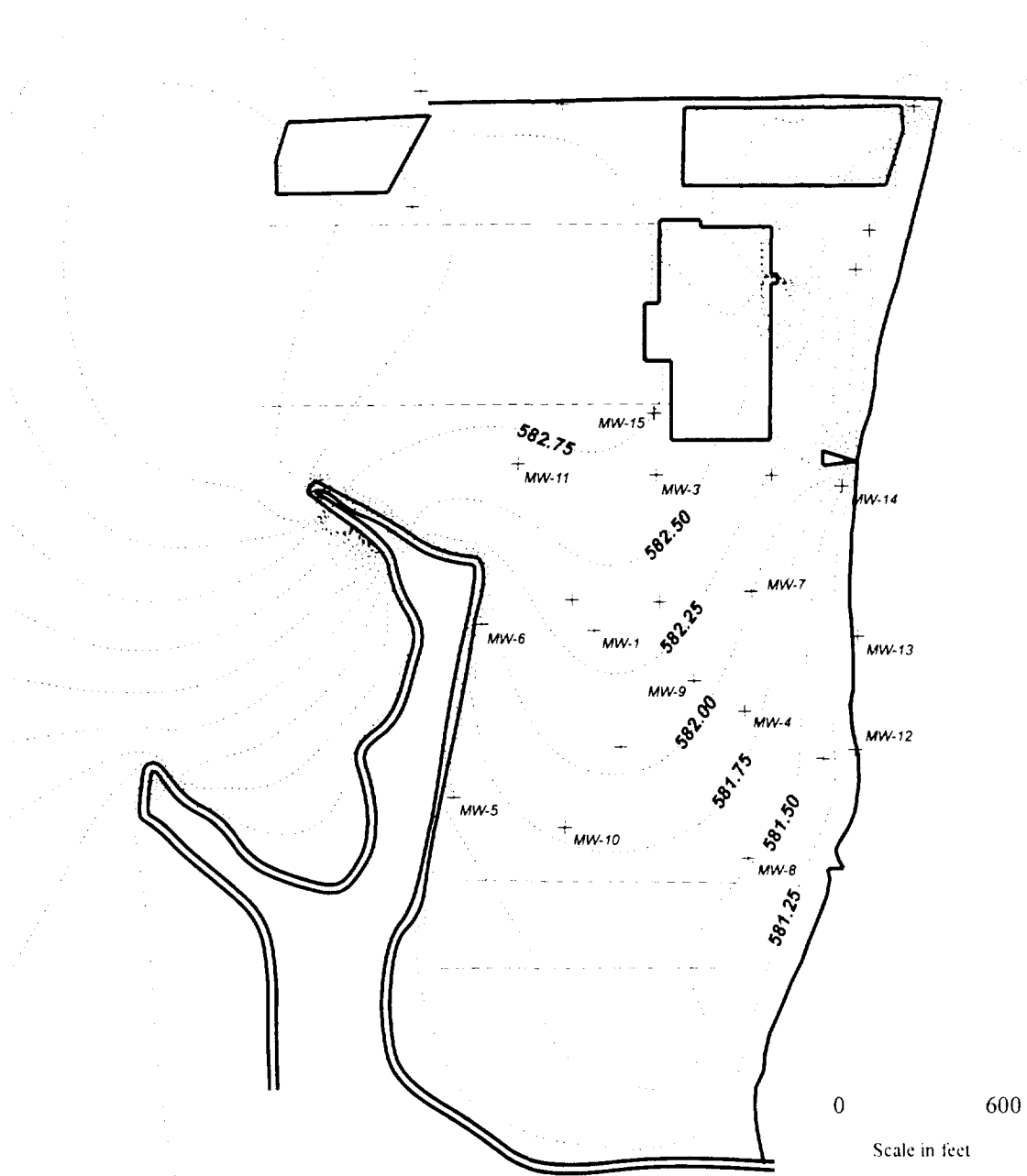
Figure 2-C-3

SIMULATED PIEZOMETRIC HEADS
1967 SHORELINE, WITHOUT PONDS

MW-15

MW-11

MW-3

MW-14

583.00

MW-7

MW-6

MW-1

582.75

MW-13

MW-9

582.50

MW-4

MW-12

582.25

MW-5

MW-10

582.00

581.75

MW-8

581.50

581.25

0   600

Scale in feet
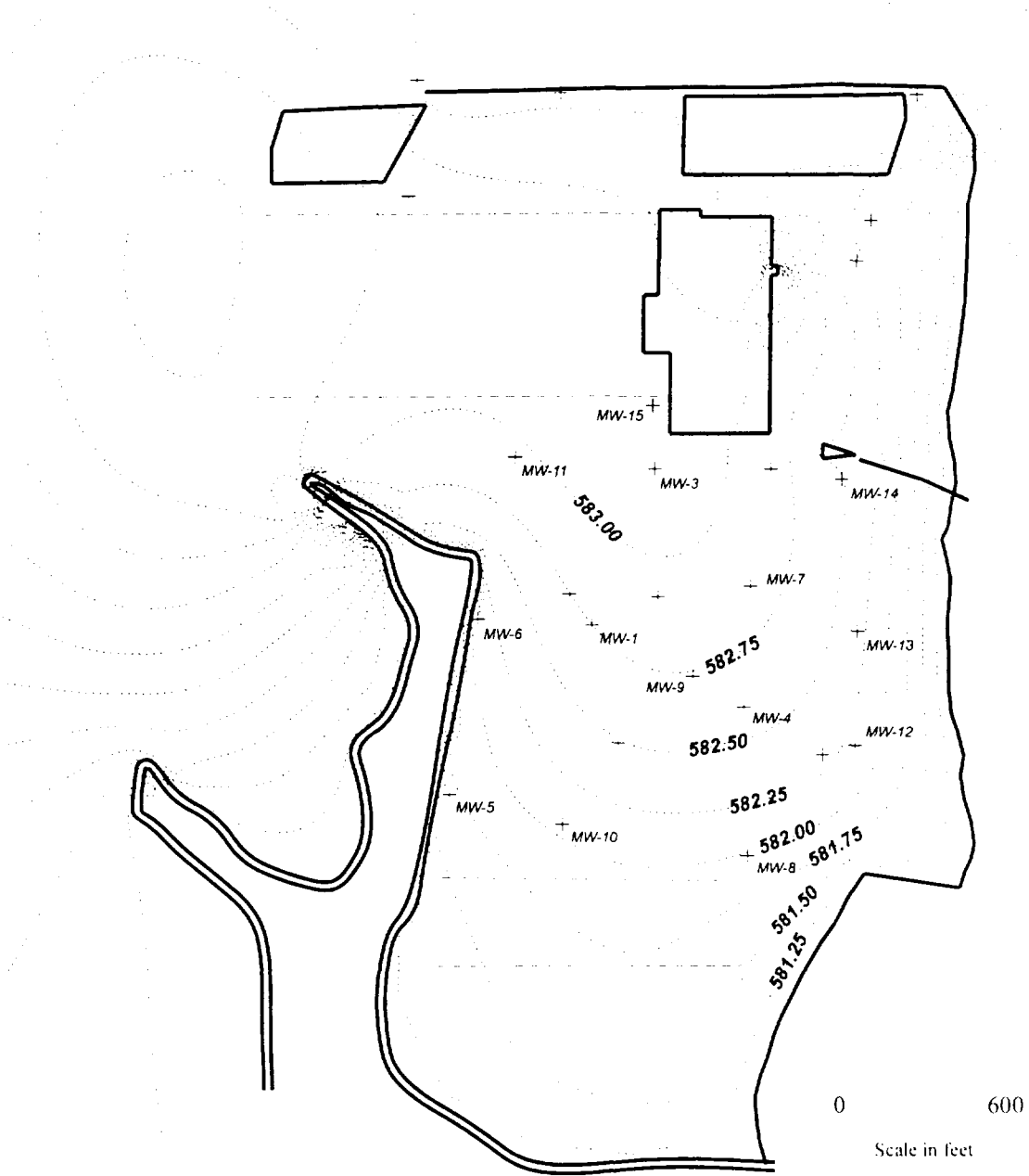
Figure 2-C-4

SIMULATED PIEZOMETRIC HEADS
1988 SHORELINE, WITHOUT SLIP NO. 4

582.75

MW-15

MW-11   MW-3   MW-14

MW-7

MW-6   MW-1   MW-13

582.50

MW-9

MW-4   MW-12

582.25

MW-5

582.00

MW-10   581.75

MW-8   581.50

581.25

0   600

Scale in feet
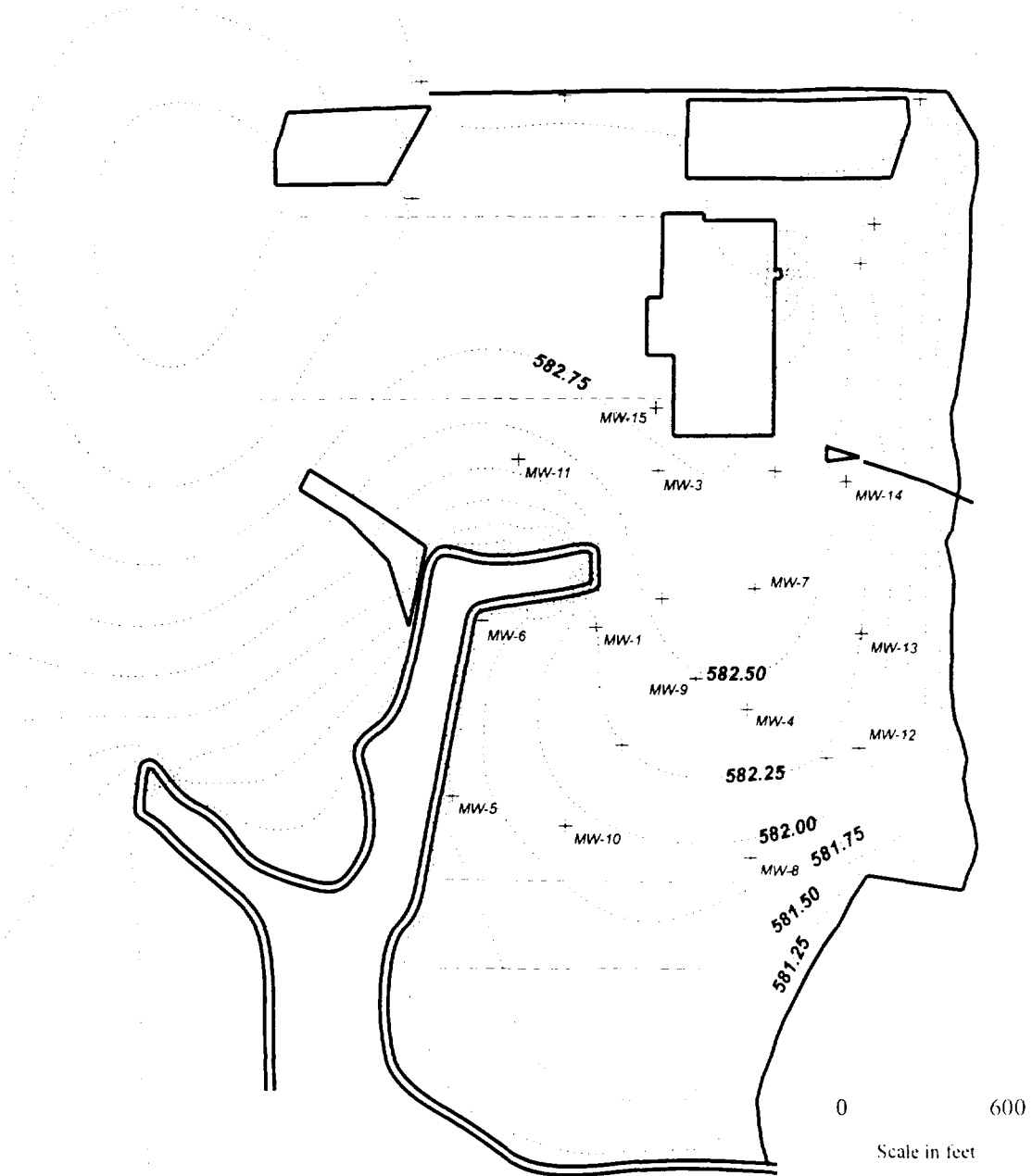
Figure 2-C-5

SIMULATED PIEZOMETRIC HEADS
1988 SHORELINE, WITH SLIP NO. 4

1988
1981
1974
MW-15
MW-11
1967
MW-3
MW-14
1988(s),1993,1997
MW-7
MW-6
MW-1
MW-13
1967(p)
MW-9
MW-4
MW-12
MW-5
MW-10
MW-8

0   600

Scale in feet
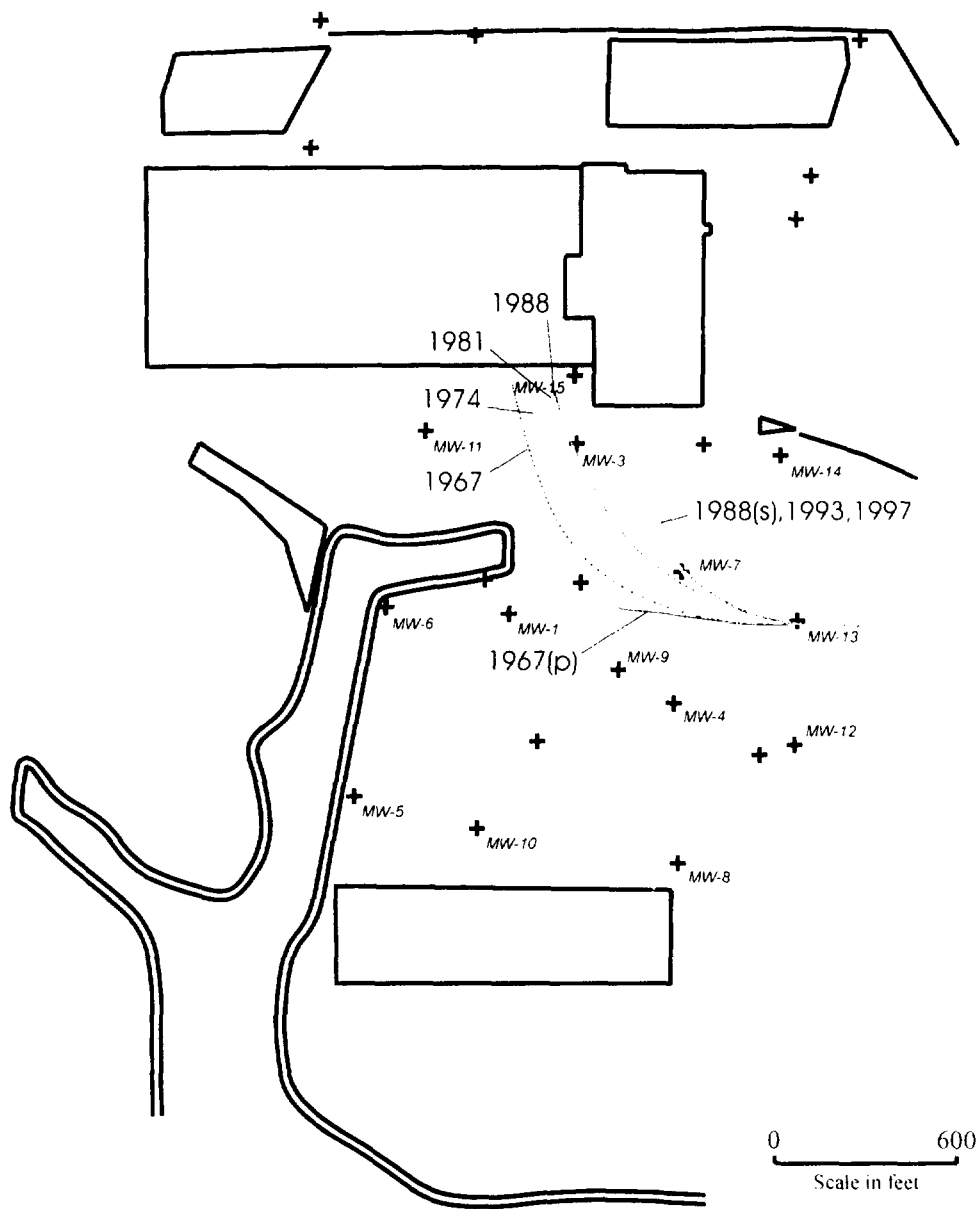
Figure 2-C-6

SUMMARY OF GROUNDWATER MODEL
PARTICLE-TRACKING PATHLINE TRACES
TO LAKE MICHIGAN

MW-15
1988
MW-11
MW-3
1967
1988(s)
MW-14
MW-7
MW-6
MW-1
1967(p)
MW-13
MW-9
MW-4
MW-12
MW-5
MW-10
MW-8

0   600
Scale in feet
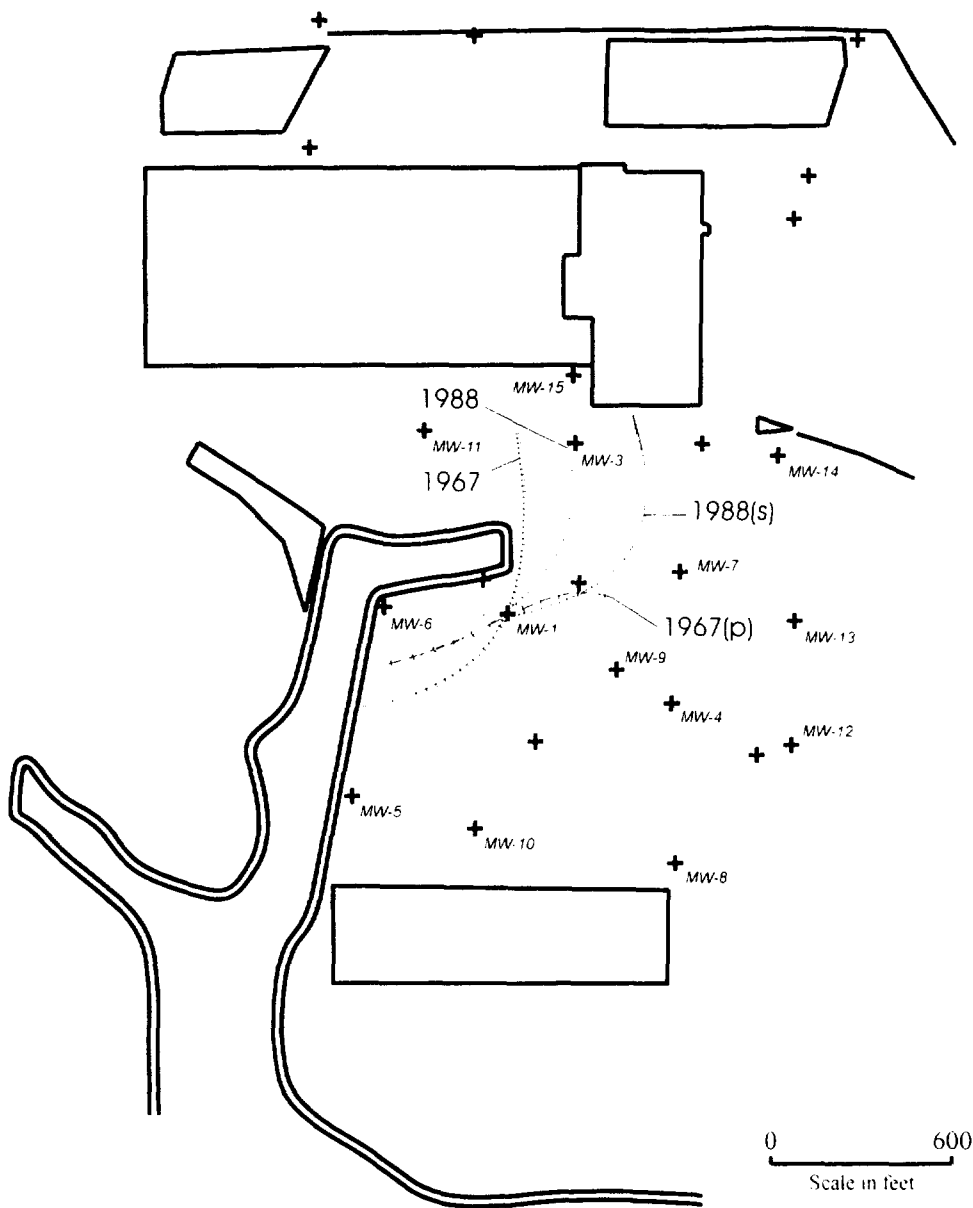
Figure 2-C-7

SUMMARY OF GROUNDWATER MODEL
PARTICLE-TRACKING PATHLINE TRACES
TO WAUKEGAN HARBOR

((

1967 Shoreline

MW-13D

Beach

Lake Michigan

Groundwater Flow Path (Tick marks represent distance
traveled by groundwater in 1 year)
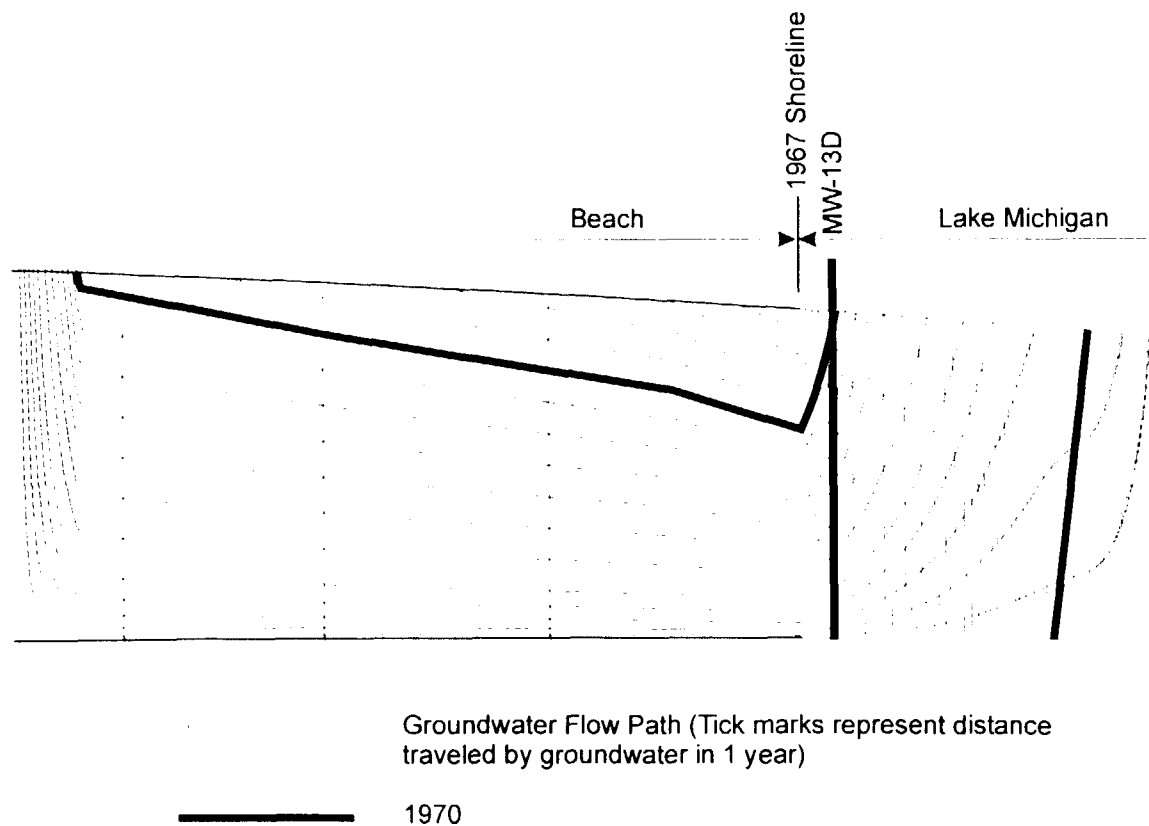
1970

Figure 2-C-8

LAKESIDE TRANSECT OF CHLORIDE PLUME IN 1970
GROUNDWATER MODEL HAS 1967 LAKE SHORELINE
WITH SIMULATED DISCHARGE OF PONDS

((

1967 Shoreline

MW-13D

Beach   Lake Michigan

Groundwater Flow Path (Tick marks represent distance
traveled by groundwater in 1 year)
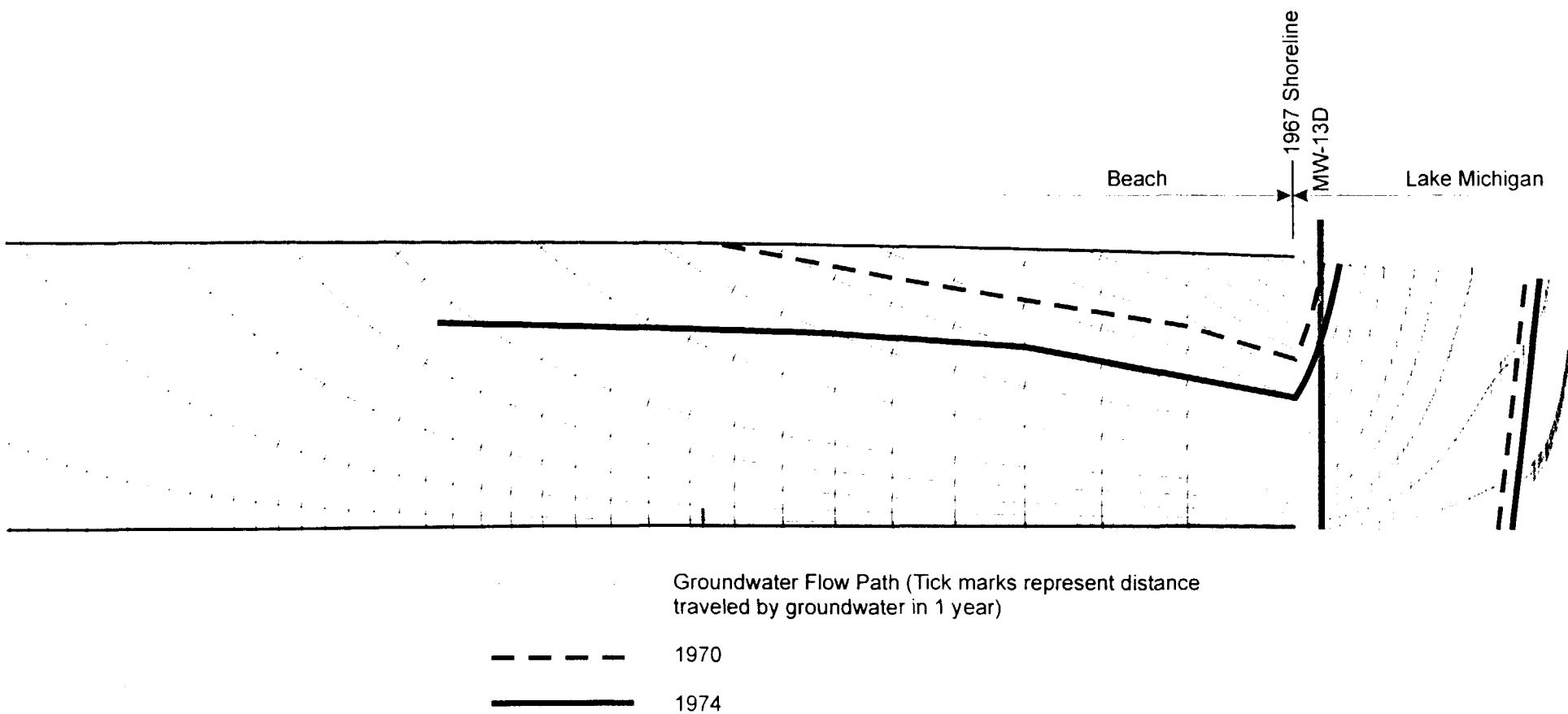
— — — —   1970

————————   1974

Figure 2-C-9

LAKESIDE TRANSECT OF CHLORIDE PLUME IN 1970 AND 1974
GROUNDWATER MODEL HAS 1967 LAKE SHORELINE
SIMULATED WITHOUT PONDS

MW-13D

1981 Shoreline

Beach

Lake Michigan

Groundwater Flow Path (Tick marks represent distance
traveled by groundwater in 1 year)
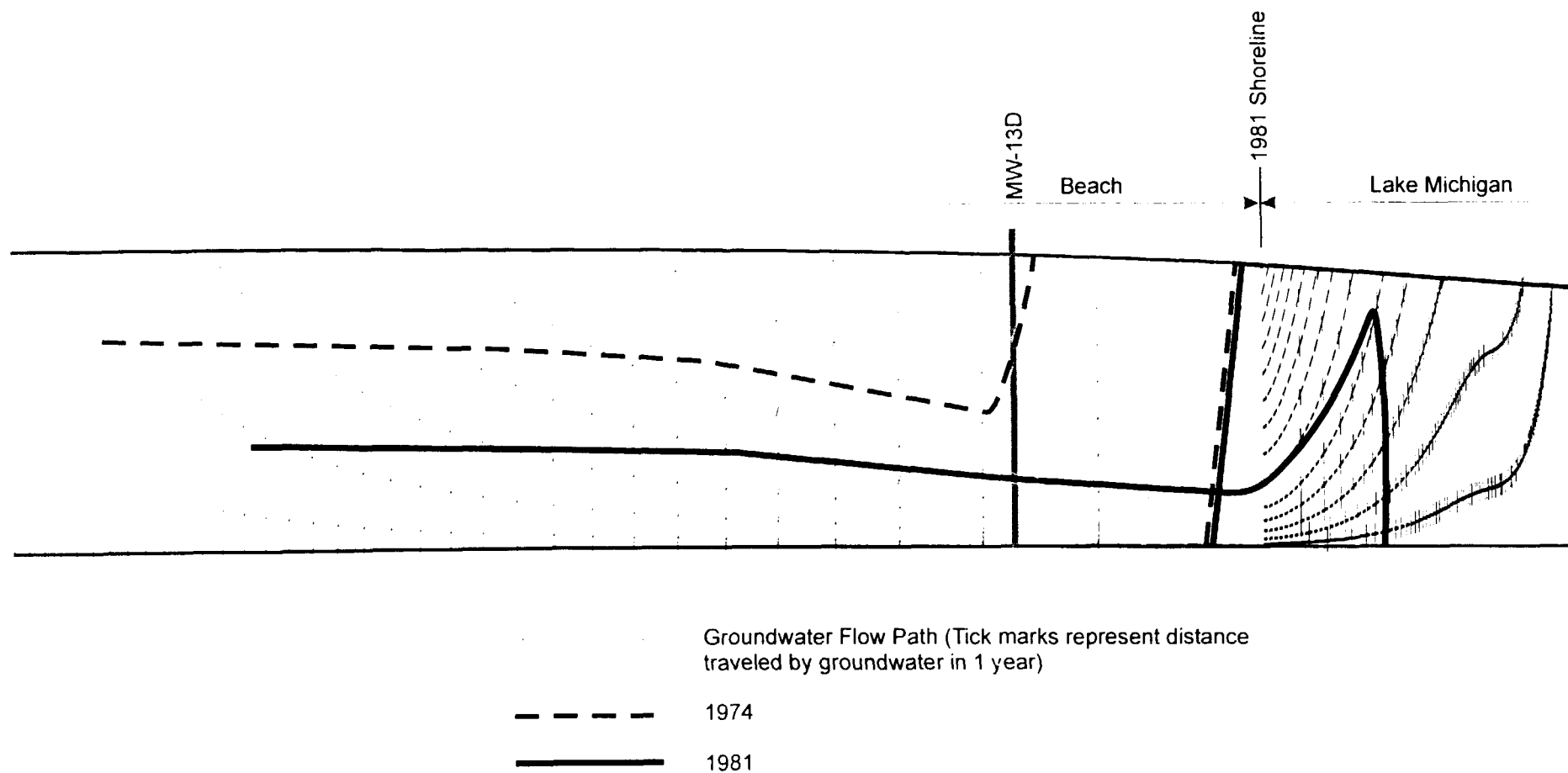
— — — — —   1974

——————   1981

Figure 2-C-10

LAKESIDE TRANSECT OF CHLORIDE PLUME IN 1974 AND 1981
GROUNDWATER MODEL HAS 1981 LAKE SHORELINE

Groundwater Flow Path (Tick marks represent distance
traveled by groundwater in 1 year)
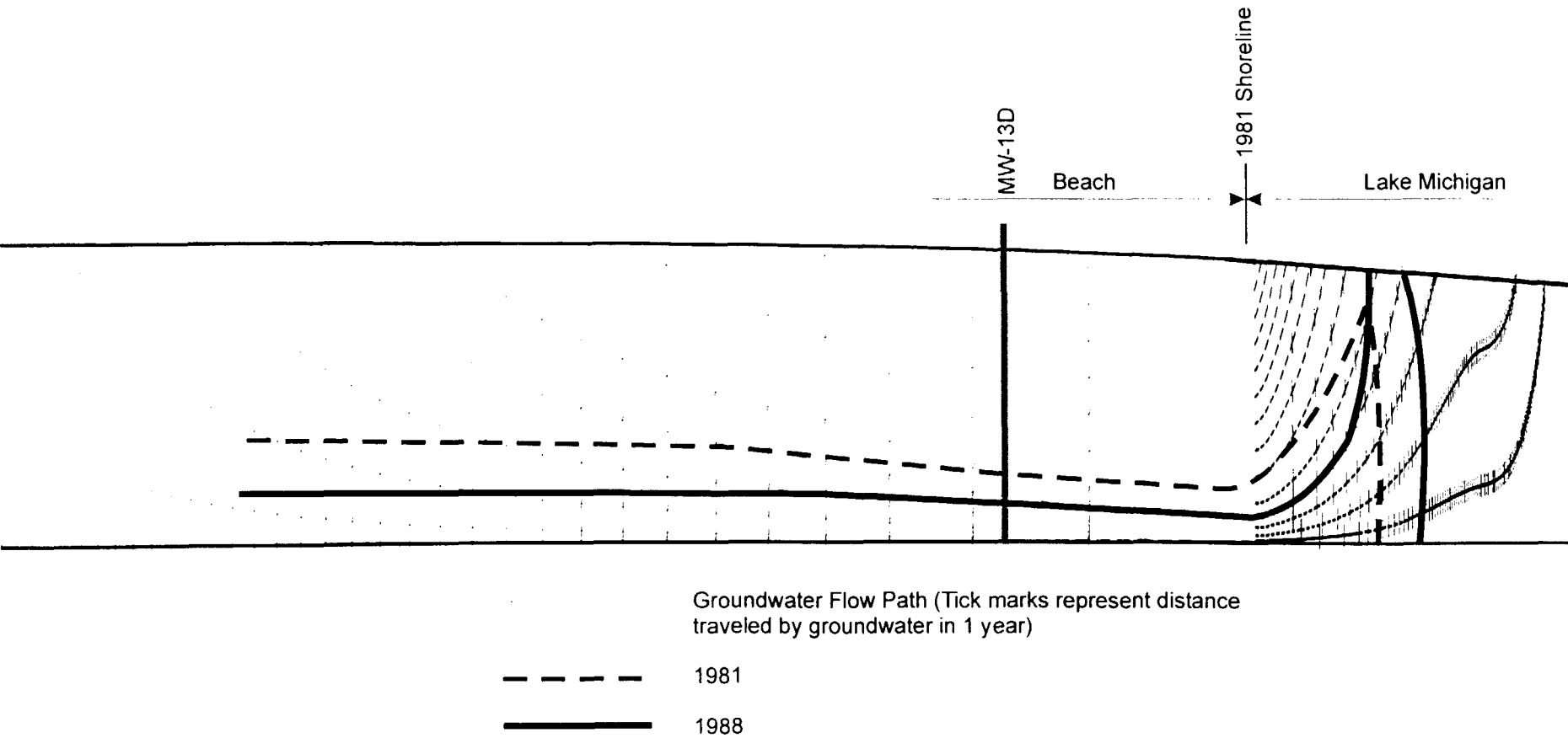
- - - - - 1981

———— 1988

Figure 2-C-11

LAKESIDE TRANSECT OF CHLORIDE PLUME IN 1981 AND 1988
GROUNDWATER MODEL HAS 1981 LAKE SHORELINE

MW-13D

1988 Shoreline

Beach   Lake Michigan

Groundwater Flow Path (Tick marks represent distance
traveled by groundwater in 1 year)
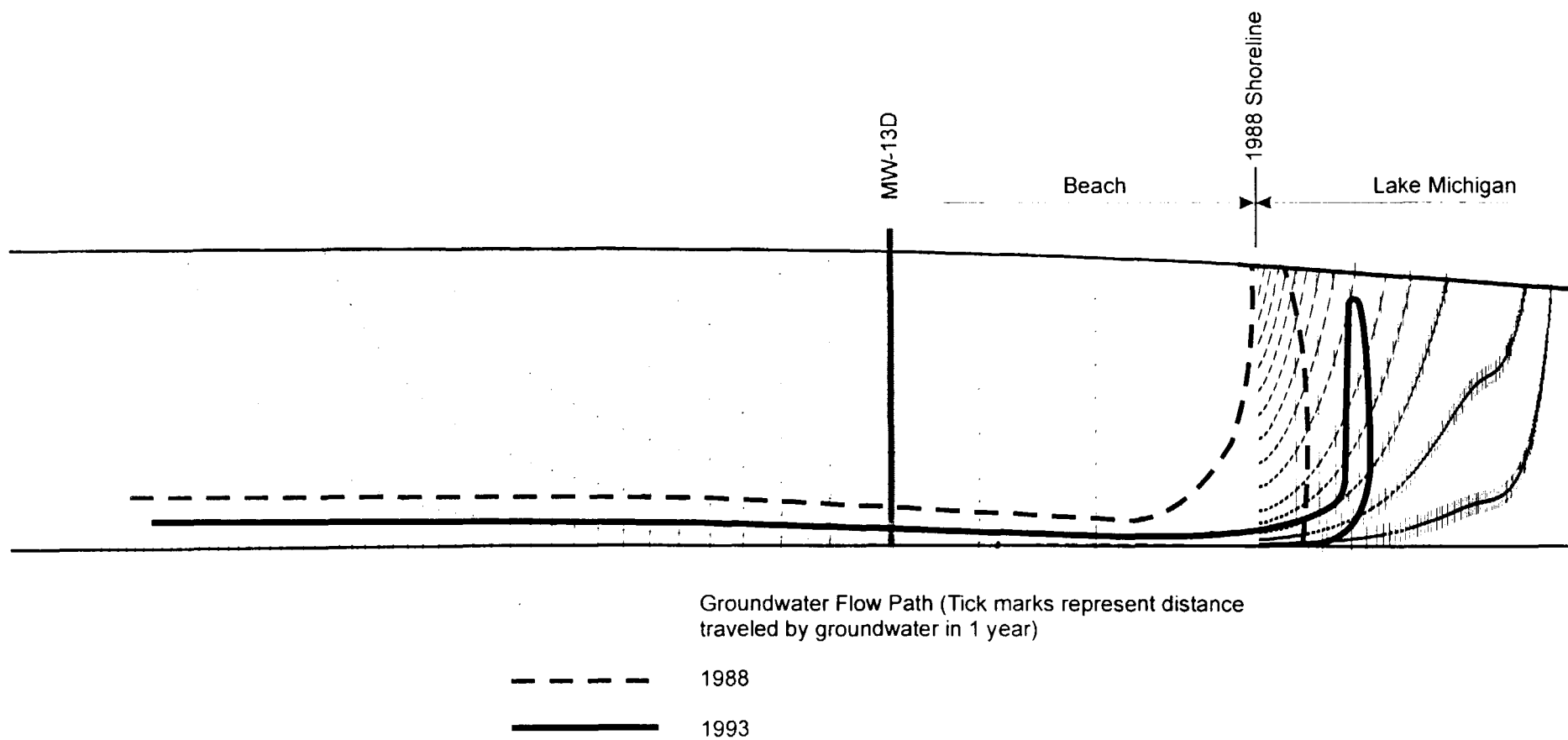
— — — — — 1988

———————— 1993

Figure 2-C-12

LAKESIDE TRANSECT OF CHLORIDE PLUME IN 1988 AND 1993
GROUNDWATER MODEL HAS 1988 LAKE SHORELINE
WITH SIMULATED SLIP NO. 4

MW-13D

1993 Shoreline

Beach

Lake Michigan

Groundwater Flow Path (Tick marks represent distance
traveled by groundwater in 1 year)
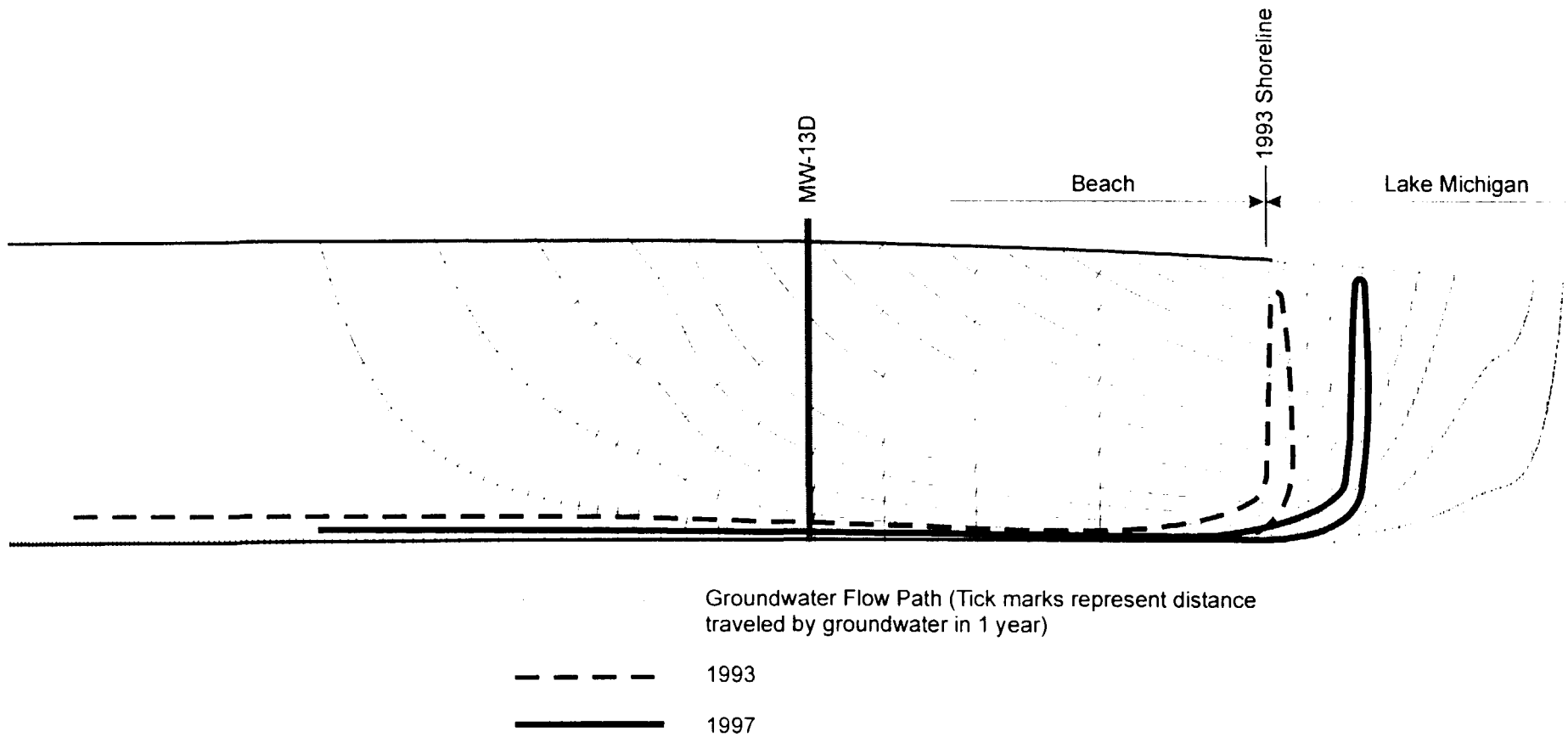
— — — —   1993

—————————   1997

Figure 2-C-13

LAKESIDE TRANSECT OF CHLORIDE PLUME IN 1993 AND 1997
GROUNDWATER MODEL HAS 1993 LAKE SHORELINE
WITH SIMULATED SLIP NO. 4

1967 Shoreline

MW-13D

1981 Shoreline

1988 Shoreline

1993 Shoreline

1970
1974
1981
1988
1993
1997
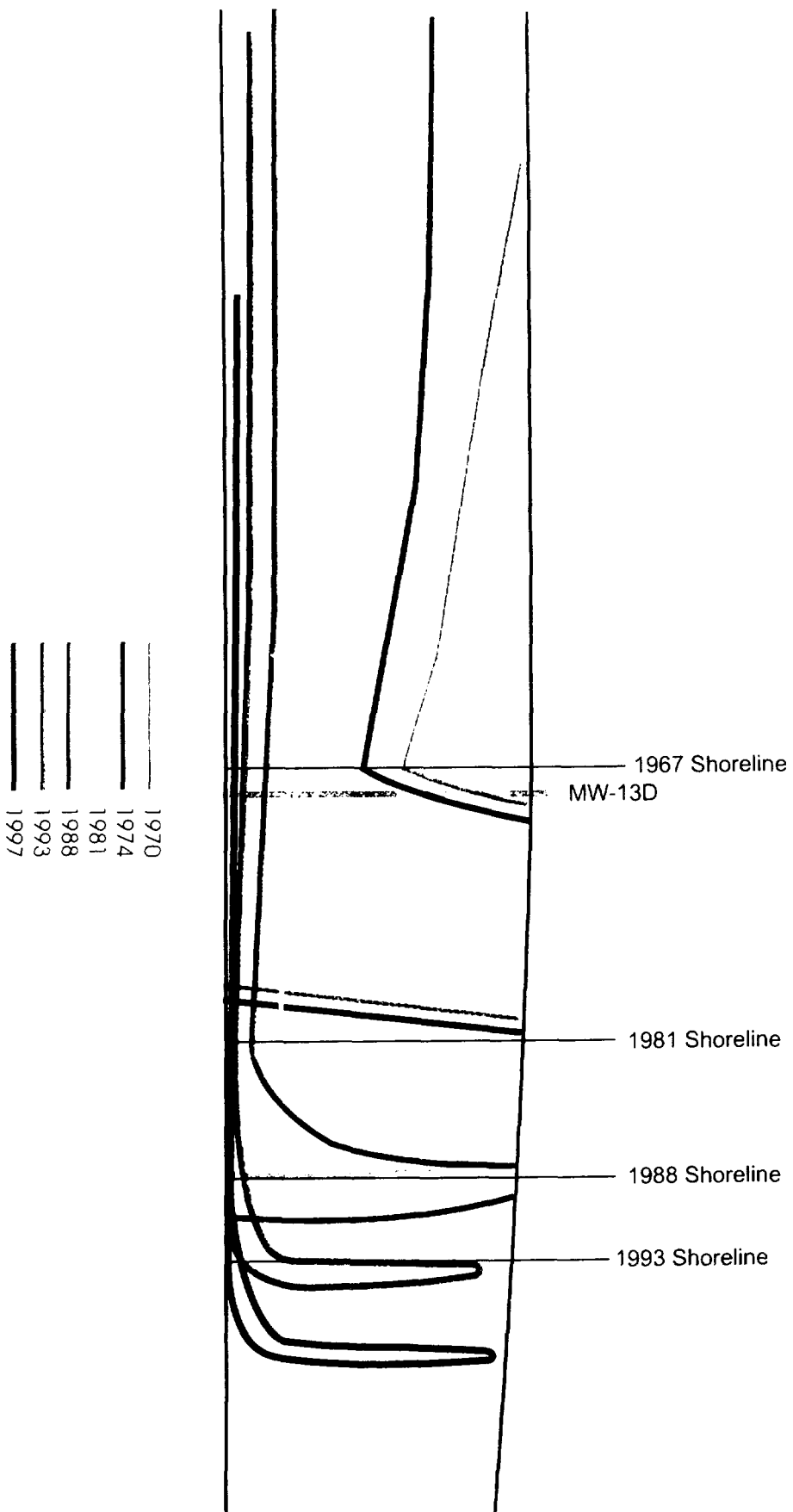
Figure 2-C-14

LAKESIDE TRANSECT OF CHLORIDE PLUME IN
1970, 1974, 1981, 1988, 1993 AND 1997

HARBOR →

MW-1

Groundwater Flow Path (Tick marks represent distance
traveled by groundwater in 1 year)
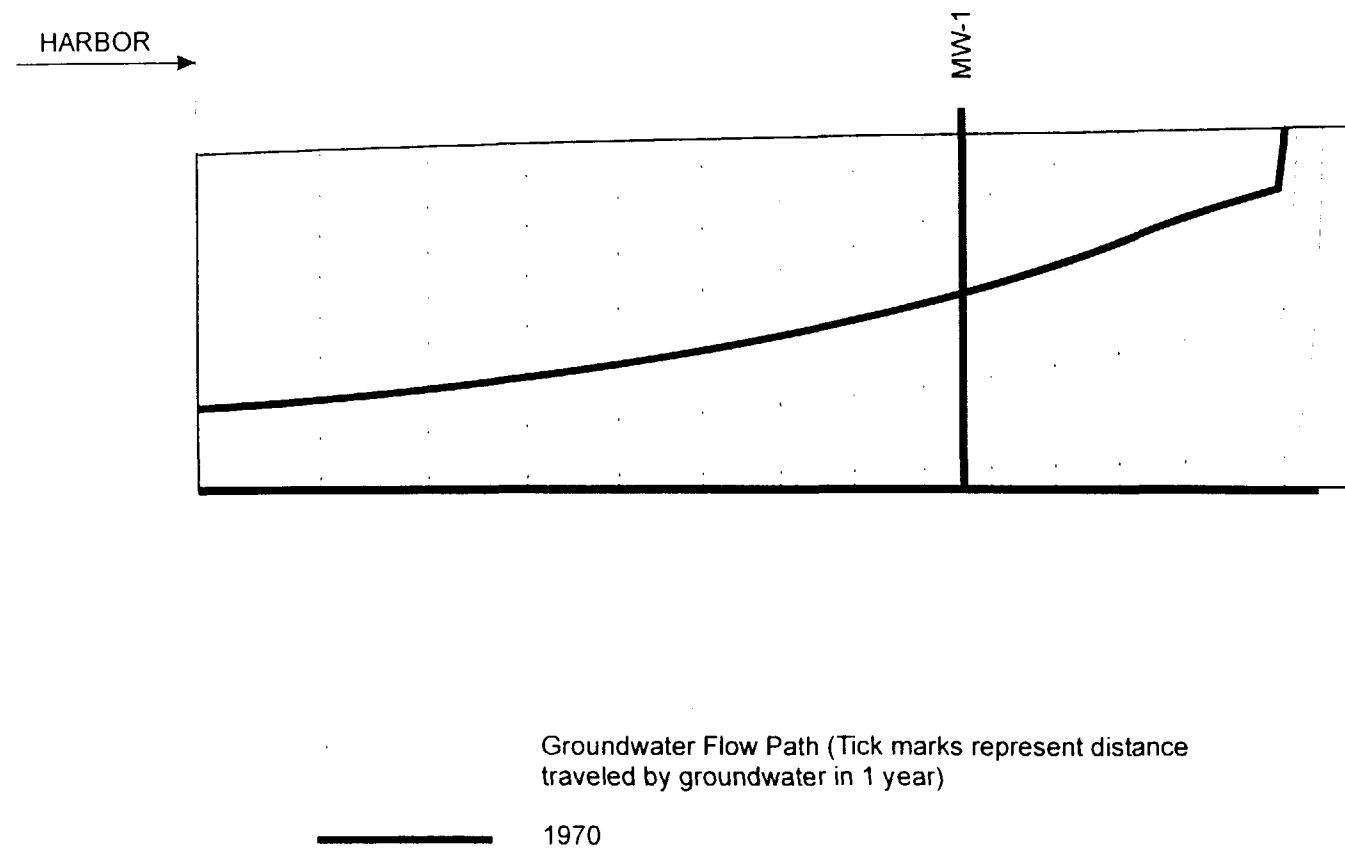
——————   1970

Figure 2-C-15

HARBORSIDE TRANSECT OF CHLORIDE PLUME IN 1970
GROUNDWATER MODEL HAS 1967 LAKE SHORELINE
WITH SIMULATED DISCHARGE OF PONDS

HARBOR

MW-1

Groundwater Flow Path (Tick marks represent distance
traveled by groundwater in 1 year)
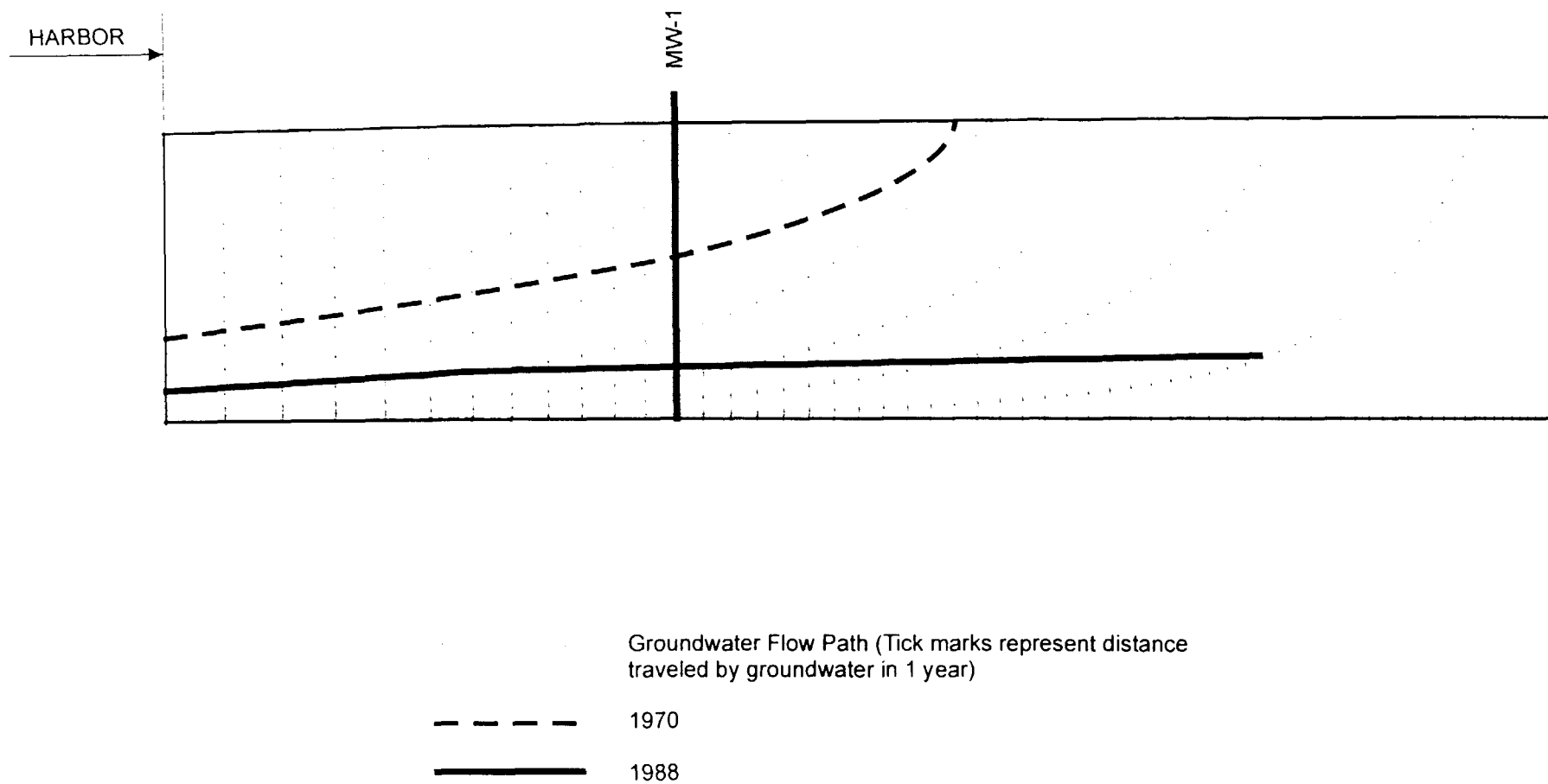
– – – – –   1970

——————   1988

Figure 2-C-16

HARBORSIDE TRANSECT OF CHLORIDE PLUME IN 1970 AND 1988
GROUNDWATER MODEL HAS 1967 LAKE SHORELINE
WITHOUT SIMULATED PONDS

((

HARBOR

MW-1

Groundwater Flow Path (Tick marks represent distance
traveled by groundwater in 1 year)
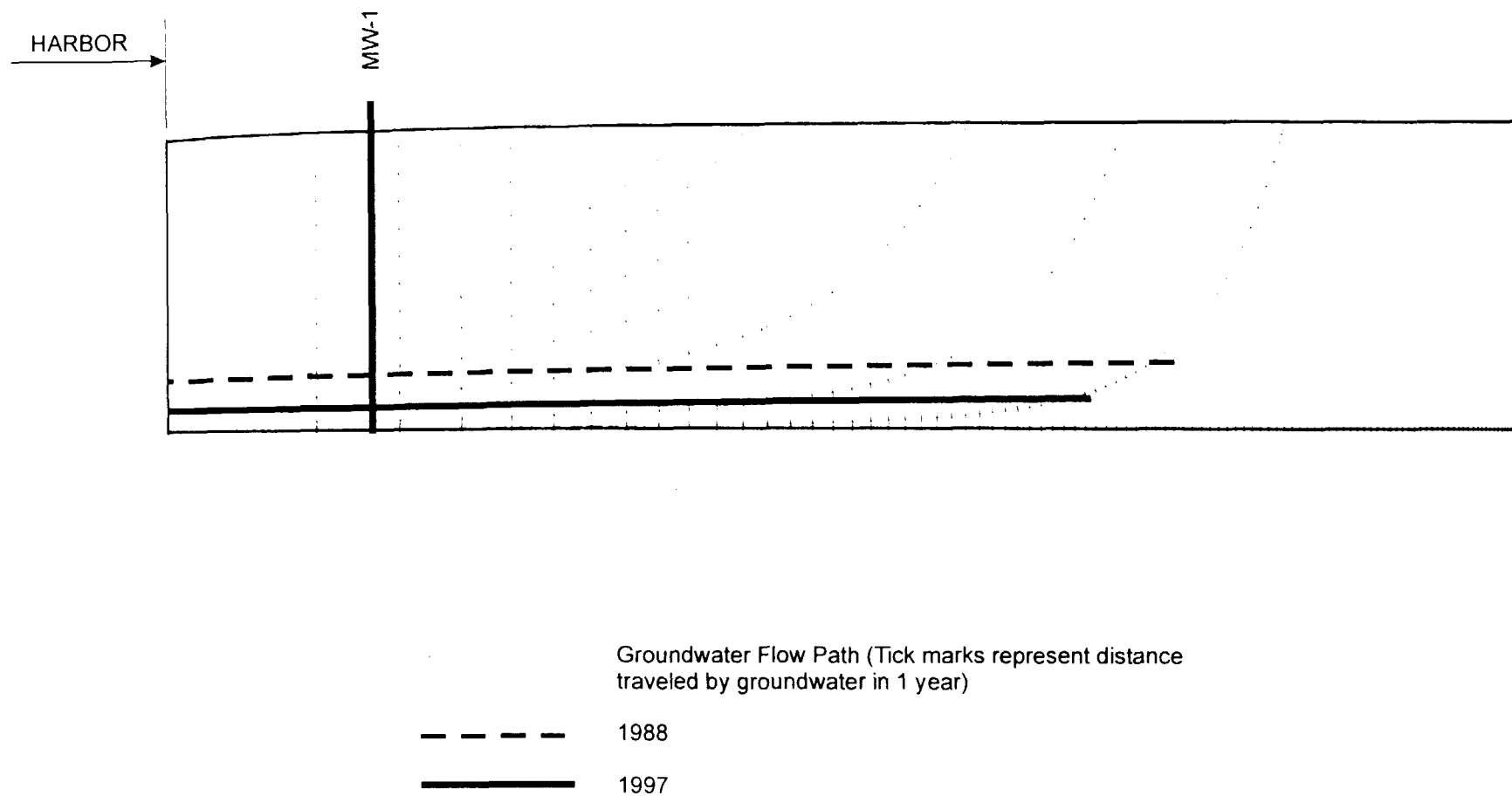
— — — —   1988

—————————   1997

Figure 2-C-17

HARBORSIDE TRANSECT OF CHLORIDE PLUME IN 1988 AND 1997
1988 GROUNDWATER MODEL WITH SLIP NO. 4

HARBOR

MW-1
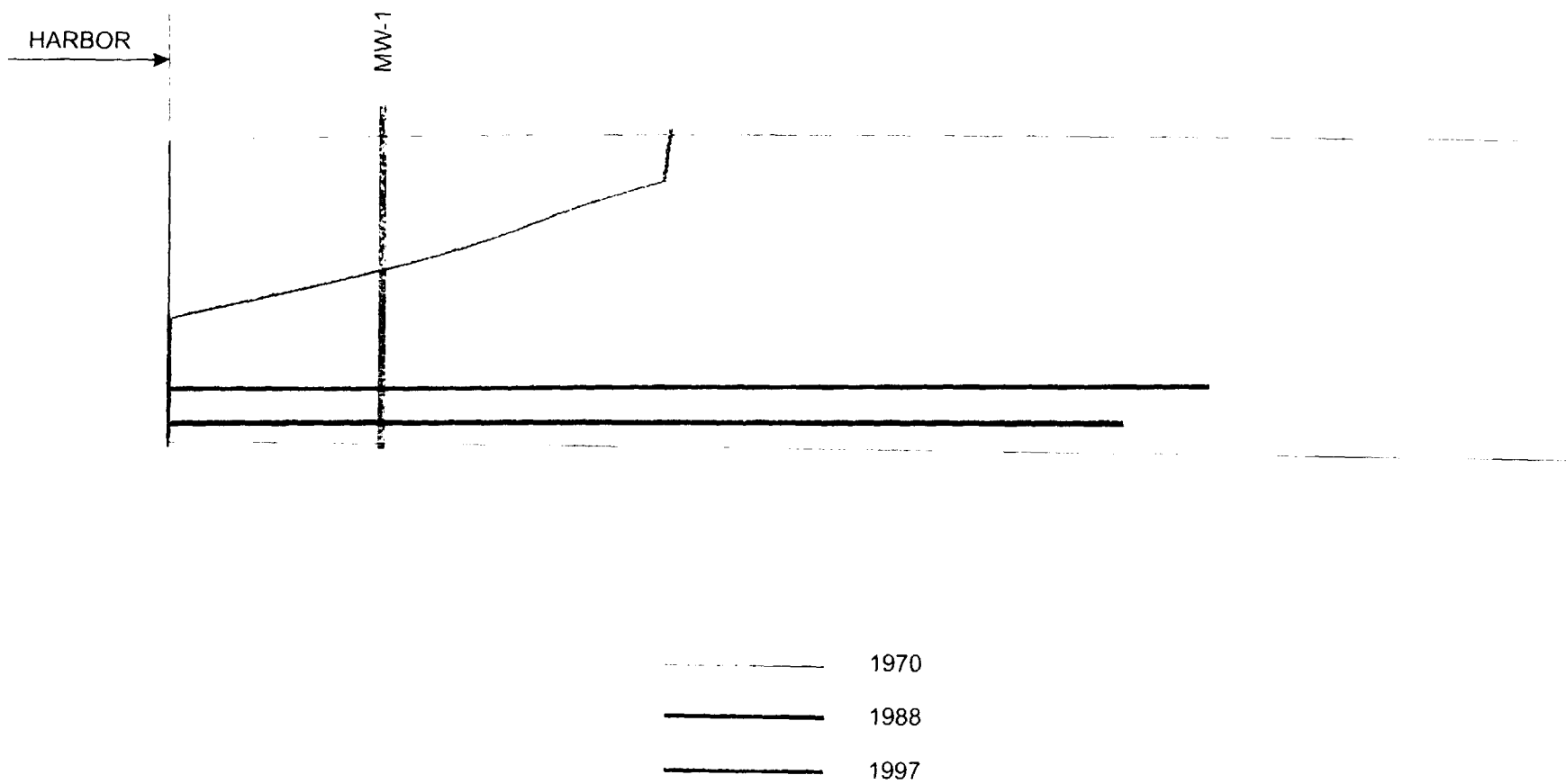
1970

1988

1997

Figure 2-C-18

HARBORSIDE TRANSECT OF CHLORIDE PLUME
IN 1970, 1988 AND 1997

1970
1974
1981
1988
1993
1997

1967 Shoreline

MW-13D

1981 Shoreline

1988 Shoreline

1993 Shoreline
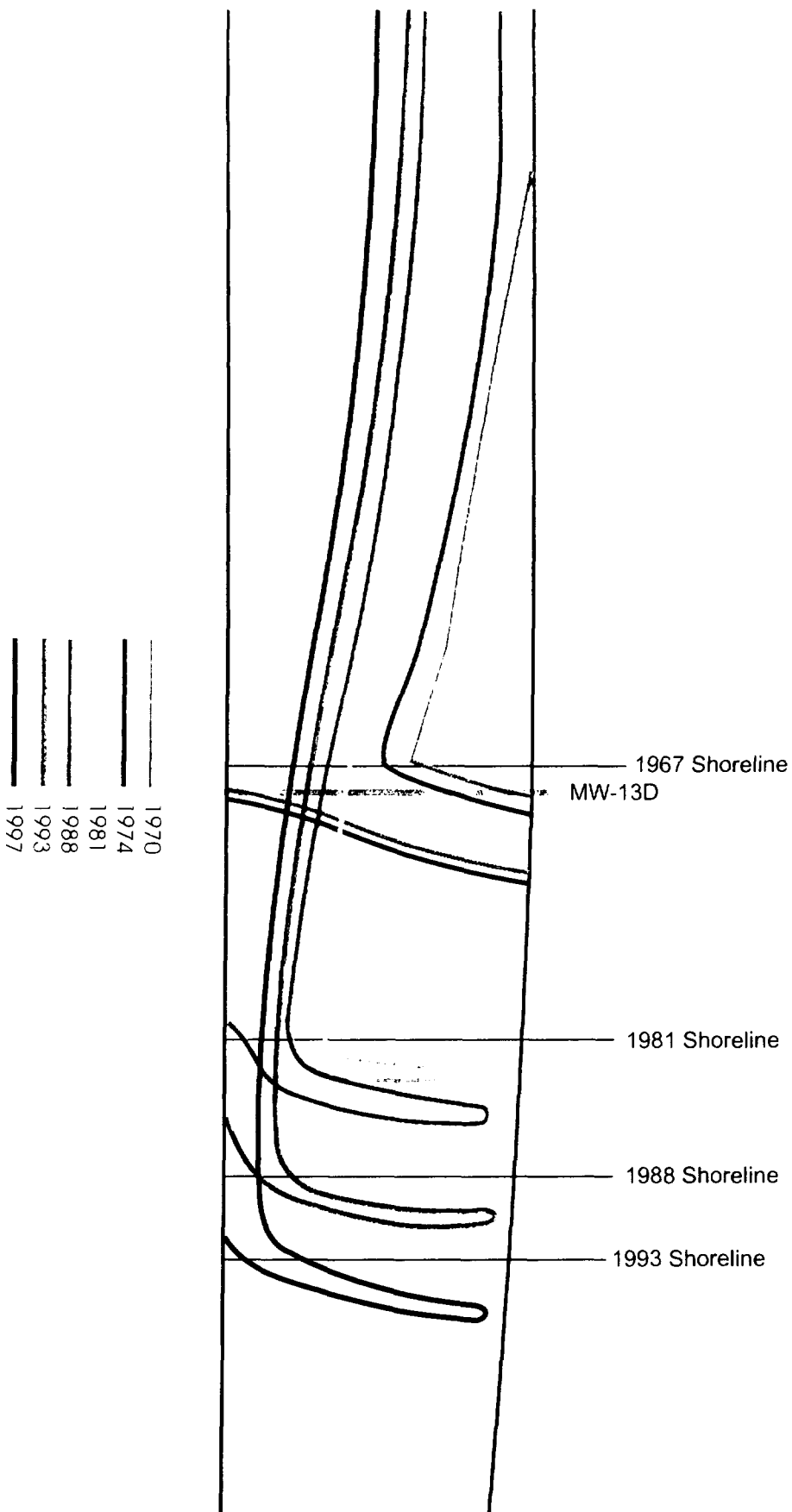
Figure 2-C-19

LAKESIDE TRANSECT OF PHENOL PLUME IN
1970, 1974, 1981, 1988, 1993 AND 1997

((

HARBOR →

MW-1
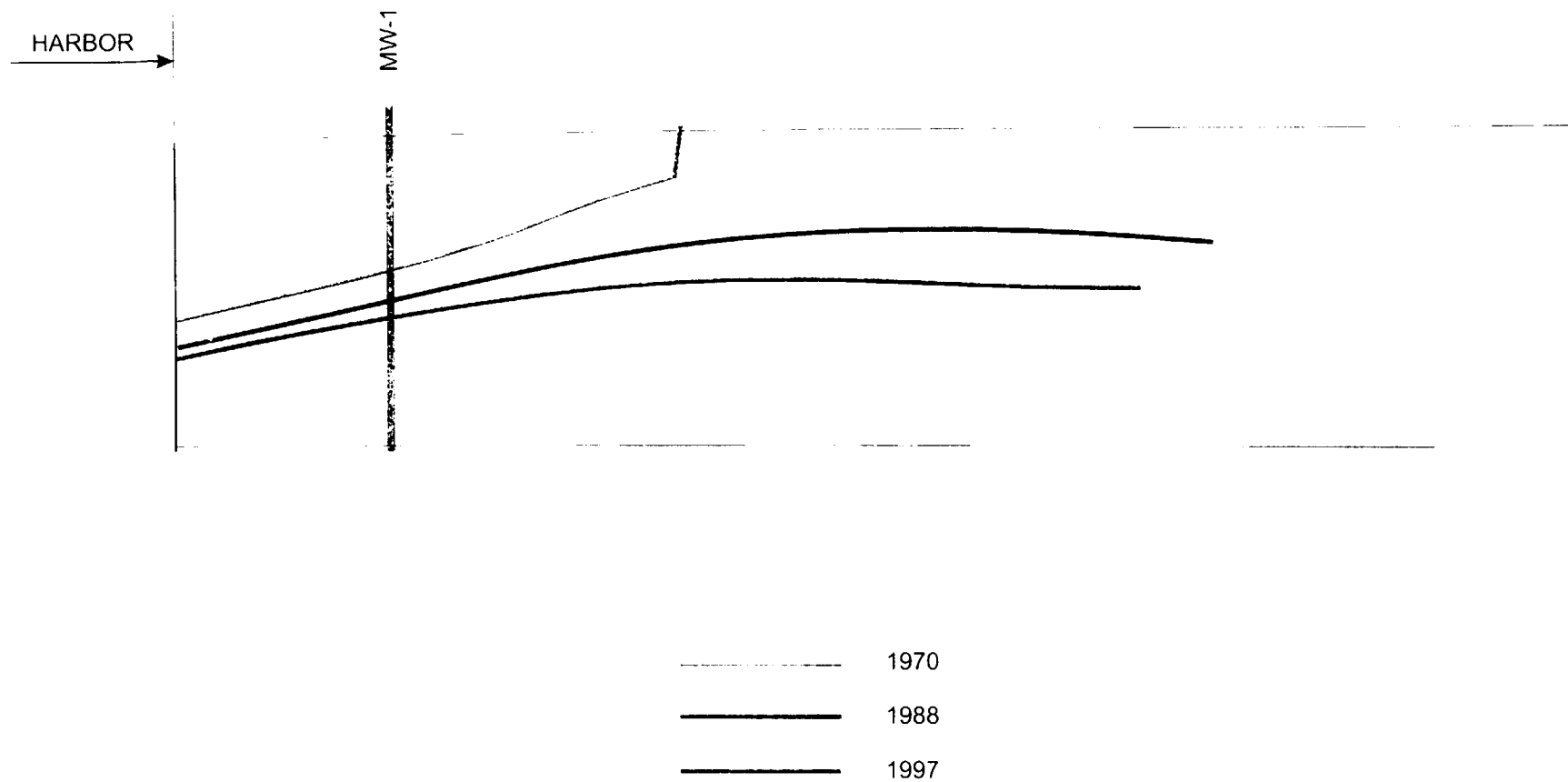
——————— 1970

——————— 1988

——————— 1997

Figure 2-C-20

HARBORSIDE TRANSECT OF PHENOL PLUME
IN 1970, 1988 AND 1997

Appendix 2-D

Groundwater Mixing with,
and Water Quality Effects on,
Lake Michigan and Waukegan Harbor

Appendix 2-D

Groundwater Mixing with and Water Quality Effects on Lake Michigan and Waukegan Harbor

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Appendix 2-D

Groundwater Mixing with and Water Quality Effects on Lake Michigan and Waukegan Harbor

Introduction

This appendix presents the FS model of groundwater mixing with surface water and the potential effects of groundwater discharges on surface water quality. The model of groundwater mixing with surface water has been updated from the RI model, in order to better represent the near-shore zone of the lake, where groundwater discharges. (Appendix 2-C presents the modeling of groundwater discharge to the lake.) The calculation of potential effects on surface water quality incorporates the post-RI investigation findings on vertical distribution of COCs in the groundwater and the refined groundwater flow modeling presented in Appendix 2-B. This modeling does not account for attenuation mechanisms that reduce the mass flux of COCs, either in the groundwater (i.e., anaerobic or aerobic biodegradation) or the surface water (i.e., chemical transformation and biological processes). Therefore, the calculated surface water concentrations based on this model should be viewed as conservative estimates of the maximum potential effect on surface water.

Surface Water Mixing Model Refinement

As discussed in Appendices 2-B and 2-C, more detailed reviews of the site water balance and the interaction of the beach and aquifer were conducted subsequent to the Remedial Investigation Report. The additional analysis showed that it would be appropriate to consider two surface water mixing zones on the lake side. These zones are the near-shore zone and the longshore current zone. The near-shore zone for this analysis is the area in which groundwater discharges to surface water. The longshore current zone is a much larger zone in which surface water flows are dominated by lake currents. The longshore current zone was the zone represented in the Waukegan Harbor surface water model described in Appendix 8-C of the February 1995 RI Report.

This portion of Appendix 2-D presents a supplementary model for the near-shore zone mixing and provides further evaluation of the flows in the longshore current zone. Mixing ratios between groundwater and surface water are derived for each zone separately. The methods and assumptions used in these calculations were expected to produce conservative estimates of mixing. The surface water current measurements obtained during the 1997 surface water sampling confirmed that the lake current estimates here are conservative for the low mixing scenarios.

Therefore, the mixing ratios presented in this appendix should be viewed as conservative measures for the attenuation of discharged contaminants in the lake and harbor.

Near-Shore Zone

The near-shore zone consists of the breaker and the wind-current zones. The breaker zone is formed when winds are from the east, north, or south. The waves produced by these winds break as they approach the shore, producing an intensely mixed area near the shore referred to as a breaker zone. However, when winds are from the west (the prevailing winds are northwesterly), no breaker zone is formed; rather, wind-induced currents are generated. These wind-induced currents cause mixing and exchange of water with deeper portions of the lake. The development of the analysis of the near-shore zone in the lake directly east of the site is presented in detail here. A similar analysis, based on wind-induced currents and measured currents for the breakwater area (swimming beach) southeast of the site, is summarized as well.

Breaker Zone

The breaker zone is an intensely mixed zone in which waves typically break as they approach the shoreline. Groundwater which enters this high-energy mixing zone is promptly dispersed. A separate breaker zone mixing model was developed to better understand the dynamics of the near-shore situation and to supplement the mixing model for the longshore current zone.

The size of the breaker zone was estimated from aerial photographs. Observations of breaker zone size were made in the area between Waukegan Harbor to the south and Commonwealth Edison Power Plant to the north. Distinct areas of breaking waves or mixing zones adjacent to the shore were visible on aerial photographs on the following dates: 7/1/54, 3/28/59, 9/18/61, 10/20/67, and 10/10/74. Other photographs were examined, but, either due to wind direction or indistinct photography, they were not suitable for determining breaker zone size. Based on the measurements from the aerial photographs, the average distance from the shore to the edge of the breaker zone is 340 feet. This breaker zone encompasses the groundwater discharge zone (from the shore to about 250 feet offshore) described in Appendix 2-C. The north-south length of the breaker zone opposite the site was measured from the breakwater near the southern edge of the site to approximately the northern edge of the site, a distance of 1,600 feet. Lake depths were taken from the Mariner's Atlas map (Gulf Publishing Co., 1988), which showed a lake depth of approximately 4 feet at a distance of 340 feet from the shoreline. The location of the near-shore zone east of the site is shown on Figure 2-D-2.

Breaker Zone Currents

Winds from the east, north, and south produce waves which create a breaker zone along the shore. These waves induce a longshore current, the strength of which is a function of the wave height, the angle at which the waves approach the shore, and the slope of the beach. The formula for the breaker current is:

$v = 20.7m \, (gH_b)^{\frac{1}{2}} \sin 2 \, \alpha_b$ (equation 4-22 from the Shore Protection Manual, Volume I, Coastal Engineering Research Center, 1984).

where: v = Longshore current velocity within the breaker zone

m = Beach slope

g = Acceleration due to gravity

H_b = Breaker height

α_b = Angle between breaker crest and shoreline

Application of this formula requires measured or estimated breaker wave heights. As a first approximation, observed breaker wave heights from the west shore of Lake Michigan in Kewaunee County, Wisconsin were used (Lee, 1975). The data and calculated breaker zone current velocities are shown in Table 2-D-1.

The calculated average, highest, and lowest longshore currents were used to compute groundwater mixing ratios with surface water. The average annual groundwater discharge to the lake east of the site (north of the north breakwater) is 22.5 gpm. The groundwater mixing ratios for breaker-induced currents are as follows:

- Average current (0.65 feet per second)   9,000 surface water : 1 groundwater
- High current (1.60 feet per second)   22,000 surface water : 1 groundwater
- Low current (0.21 feet per second)   2,900 surface water : 1 groundwater

Note that the above mixing ratios do not account for exchange between the breaker zone and deeper waters due to flows perpendicular to the shore. Thus, these mixing ratios underestimate the actual mixing that would be expected for the breaker zone.

Wind Current Zone

Westerly winds do not develop a breaker zone. However, currents and mixing are induced by such winds. The velocity of wind-induced currents are approximately 2 percent of the wind velocity (Wetzel, 1975). In cases where the transfer efficiency of wind velocity to water velocity is inefficient, the water velocity may be 1.3 percent of the wind velocity (Wetzel, 1975). The zone for calculation of groundwater mixing by these wind-induced currents will be somewhat different than the breaker zone, because the breaker zone size is defined by lake conditions. In contrast, in this analysis, the wind current zone is defined by the size of the groundwater discharge zone. For the wind-induced current zone, the distance from the shore to the edge of the zone was taken to be 250 feet. The location of this zone is shown on Figure 2-D-2. Calculation of the mixing in this zone was based on a northwesterly wind of 4.5 meters per second. This wind velocity was the average wind velocity used in risk assessment calculations (U.S. EPA, 1995). This wind velocity is equivalent to 14.8 feet per second or 10 miles an hour.

While the breaker zone was well mixed over its full extent, the same conditions were not assumed for the wind current zone. The wind current model assumes that for the component of flow perpendicular to the shore, the wind affects only the upper half of the water. The lower half flows towards the shore to replenish the water being driven out from the shore by the wind. For the component of flow parallel to the shore (north-south flow), the wind affects the full depth of the water. The calculated mixing ratio between surface water and groundwater is 12,000:1. If the low efficiency of wind transfer coefficient and a 5 mph (2.25 m/s) wind is used, the mixing ratio is approximately 3,700:1.

During periods of no wind, mixing activity will gradually decline. There are generally few windless periods at the edge of a large body of water like Lake Michigan. During calm periods, winds may still develop near the lake because of daily cycles of differential heating of land versus water. The long, unobstructed fetch over the water also contributes to fewer and shorter calm periods than would be expected inland. In fact, the Waukegan wind rose on Figure 2-D-1 shows that, for wind measurements taken at a weather station near the lakeshore in Waukegan (1951–1964), winds were calm only about 1.4 percent of the time. Observation of the lake while sampling during "windless" periods found that currents persist, even when the winds and lake appear calm. The observed currents in the near-shore zone off the site during the 1997 sampling (low wind conditions) ranged from 0.032 m/s (6.3 ft/min) to 0.084 m/s (16.6 ft/min). These measurements are higher than the low currents used in the mixing model analysis (0.029 m/s).

Conclusion—Lake Near-Shore Zone

On the basis of this evaluation, the normal mixing ratio between groundwater and surface water in the lake near-shore zone is 12,000:1 or higher. The mixing ratios easily range in excess of 22,000:1 for waves of 2 feet high or more Even under "calm" low mixing conditions, mixing ratios of 2,900:1 or more would be expected.

Breakwater Area

The breakwater area lies southeast of the site in the area between the north breakwater and the north harbor wall, as shown on Figure 2-D-2. The public swimming beach is in this area. The estimation of surface water currents in this area used wind-induced currents and measurements, not breaker current calculations, as the development of a breaker zone is likely to be affected by the breakwaters. The low current, 0.013 m/s (2.6 ft/min) was measured during the 1997 sampling. The average current, 0.064 m/s, is for a 4.5 m/s (10 mph) wind. The high current, 0.27 m/s, is for a 13.5 m/s (30 mph) wind. The mixing ratios for these cases are: 1,600:1 for the low current, 7,600:1 for the average current, and in excess of 30,000:1 for the high current.

Longshore Current Zone

The Waukegan Harbor surface water model described in Appendix 8-C of the February 1995 Remedial Investigation Report describes mixing with Lake Michigan. This mixing occurs in the longshore current zone, also referred to as the littoral drift zone. Analysis of the lake current data collected by Argonne National Laboratories (Harrison, 1979) is explained and incorporated into the RI model in this appendix.

The RI model uses a mass balance approach, mixing the surface water driven by lake currents with the groundwater discharging into the zone. The model uses a zone of surface water that extends approximately 2,700 feet offshore and runs approximately 2,700 feet north to south as shown on Figure 2-D-3. The zone extends from the beach to a water depth of approximately 20 feet. The actual longshore current zone extends somewhat further offshore than the 2,700 feet used in this analysis, so the actual mixing is expected to be somewhat greater than the estimates calculated using this model. The breaker zone area was not excluded from this model because the breaker zone is small compared to the longshore current zone (about 1.6 percent of its volume), so there is little effect from including or excluding the breaker zone.

Lake Current Analysis

In the RI Lake Michigan mixing model, the lake currents used for the mixing calculations were based on a qualitative review of the results from the Argonne 1979 study. These data have now been analyzed quantitatively to provide a better basis for estimating the mixing in the longshore current zone. The quantitative analysis of the data covers the full period of the Argonne 1979 study, April 26 to July 29, 1979, using four points to characterize diurnal current measurements. These four points are the current at midnight and three other points to represent the high, low and typical currents for the remainder of the day. These four daily values were then used to compute the average current for each day.

Figure 2-D-4 shows the daily average velocities for the current as well as a plot of the four points used to represent the current diurnal variability. The current frequency distribution is shown on Figure 2-D-5. The time-weighted average of the measured current velocities is 0.082 meters per second. Less than 10 percent of the velocity readings were lower than 0.015 meters per second (i.e., this velocity was exceeded 90 percent of the time.) Such low velocities were not sustained for more than four successive days during the period of study. Less than 10 percent of the velocities were greater than 0.158 meters per second (i.e., this value was higher than 90 percent of the velocities.)

The surface water mixing model for the longshore current zone includes all the groundwater discharges from the Waukegan Harbor model, the breakwater area, and the lake near-shore area. The dilution factor for groundwater to surface water for the average current is about 50,000:1. For currents at the lower 10 percent level, the dilution factor is approximately 9,000:1. At the 90 percent level, the dilution ratio is about 90,000:1. The low mixing ratio of 9,000:1 is representative of short periods of less than four days. Therefore, it should not be used in computations that require representative concentrations with significant exposure durations.

Conclusion—Longshore Current Zone

The quantitative analysis of the Lake Michigan longshore current zone mixing suggests that the representative mixing ratio is 50,000:1. The longshore current zone model does not account for any currents perpendicular to the shoreline. Therefore, the calculated mixing ratios underestimate the total actual mixing that would be expected.

Mass Loading Estimates

Mass loadings from the groundwater to the surface waters of Waukegan Harbor, the breakwater area, and Lake Michigan are presented in Appendix 5-D. The mass flux estimates presented below incorporate the 1996/97 groundwater data. The "No Action" alternative mass flux estimates from Appendix 5-D are used here to calculate potential effects on surface water quality. The groundwater model on which these mass flux calculations were based is the refined model described in Appendix 2-B. These mass flux estimates incorporate data and modeling refinements, so this work supersedes the RI mass flux estimates, which were presented in Appendix 8-A of the RI Report.

The peak mass fluxes to the surface water for the No Action case (see Appendix 5-D) are summarized in Table 2-D-2. These mass fluxes are from various times, in order to represent the highest estimated mass flux for any receiving water. These mass fluxes will not be sustained over time, as is evident from the graphs of mass flux over time in Appendix 5-D. For the Waukegan Harbor fluxes, the current (1997) flux was used, as the flux modeling shows a decline in the next few years.

Table 2-D-2 shows the peak mass fluxes for ammonia, phenol, and arsenic. Other COCs such as benzene and cyanide are not shown in this analysis because, with concentrations 100 times lower (or more) than the phenols and ammonia concentrations, their potential contributions to surface water concentrations are proportionately small.

Table 2-D-2 also shows the groundwater discharge to each surface water area, the amount of discharge attributed to the high COC zones in the groundwater (the lower one-sixth of the sand aquifer), and the average concentrations for ammonia, phenol, and arsenic in that high COC zone in the groundwater. The groundwater discharge segments (i.e., AB, BC, etc.) referenced in Table 2-D-2 are shown on Figure 2-D-6.

The Table 2-D-2 peak mass fluxes and the groundwater to surface water mixing models are used to estimate potential effects of groundwater discharge on surface water quality. An average, low, and high mixing case was developed for each area, as described in the mixing models above. The calculations for the lake near-shore zone east of the site are summarized in Table 2-D-3. For the breakwater area, Table 2-D-4 provides the summary. The Waukegan Harbor model summary is in Table 2-D-5. Table 2-D-6 is for the longshore current zone of Lake Michigan. The loading to the longshore current zone uses the combined groundwater flows from the harbor, breakwater area,

and near-shore lake. Again, the peak loading over time was used. The individual area peaks do not sum to the longshore current zone peak, as the individual area peaks occur at different times.

The sensitivity analysis done in the RI (RI Appendix 8-A) showed that the mass flux was directly proportional to the groundwater flow rate and the proportion of the sand aquifer groundwater with high COC concentrations used in the estimates. The range of groundwater flow rates from the RI sensitivity analysis is 20 percent to 150 percent of the modeled rate. The range of the proportion of the sand aquifer groundwater with high COC concentrations, based on the 1997 beach transect data, is 70 percent to 150 percent of the modeled case (one-sixth of the groundwater column). The groundwater flow and COC flux ranges are small compared to the range in surface water mixing ratios. Therefore, no analysis of sensitivity based on variations in groundwater conditions is presented here.

Conclusions

Table 2-D-7 summarizes the results of the calculation of the potential effect on surface water quality from the peak groundwater mass fluxes. Given the conservative nature of the estimated mass fluxes (peak mass flux, no degradation or mass loss in the groundwater) and mixing model, the computed values should be considered to overestimate the potential effects on surface water.

The state's surface water quality standards for the receiving surface waters are shown in Table 2-D-7, as are National Ambient Water Quality Criteria for the Protection of Aquatic Life. The modeling and calculations show that no exceedances of standards are projected under any scenario for Waukegan Harbor or for the breakwater area. The near-shore zone of the lake shows no exceedances of state surface water quality standards; exceptions are for ammonia under the lowest mixing scenario, and for phenols under all scenarios. None of these calculated surface water concentrations exceed aquatic life protection criteria. Phenols are subject to biodegradation in the groundwater and surface water, which the modeling did not account for, and which is potentially a large enough effect to eliminate the computed exceedances. No exceedances were found for the longshore current zone, except for phenols under the lowest mixing case. Degradation in the groundwater and surface water would be expected to reduce this exceedance to below surface water standards.

This analysis shows there is no threat of arsenic exceedances for the surface water at any time. Given the conservative nature of this analysis, it is unlikely that exceedances of surface water standards due to groundwater discharges will be observed now or in the future. None of the

estimated concentrations exceed criteria for protection of aquatic life. None of the estimated concentrations exceed criteria for protection of human health. The calculated surface water concentrations, even using very conservative assumptions (peak mass flux rates and ignoring natural degradation mechanisms), are fully protective of human health.

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Table 2-D-1

Breaker Zone Currents

	Data from Lee, 1975[1]				Waukegan[2] (Calculated)	Computed Waukegan Current
	α_b Breaker Angle with Beach, degrees	m Beach Slope	H_b Breaker Height (ft.)	Current Velocity (ft/sec.)	m Beach Slope	v Current Velocity (ft/sec.)
	12	0.1	0.8	0.48	0.012	0.52
	10	0.1	1.2	0.52	0.012	0.52
	13	0.08	0.9	0.50	0.012	0.59
	5	0.12	1.3	0.43	0.012	0.28
	5	0.11	1.4	0.74	0.012	0.29
	5	0.01	1.9	0.67	0.012	0.34
	16	0.03	0.7	0.12	0.012	0.61
	6	0.04	0.6	0.24	0.012	0.22
	27	0.05	0.2	0.29	0.012	0.57
	25	0.05	0.2	0.16	0.012	0.52
	6	0.05	0.5	0.082	0.012	0.21
	26	0.08	2.1	1.43	0.012	1.60
	28	0.05	1.6	0.57	0.012	1.47
	26	0.04	1.4	0.66	0.012	1.32
Average	—	—	—	0.49	—	0.65
Maximum	—	—	—	1.43	—	1.60
Minimum	—	—	—	0.082	—	0.21

Computed Waukegan Current obtained using Longshore Current Velocity Equation:

$$v = 20.7m \, (gH_b)^{\frac{1}{2}} \sin 2 \, \alpha_b$$

where:
v = Longshore current velocity within the breaker zone
m = Beach slope
g = Acceleration due to gravity
H_b = Breaker wave height
α_b = Angle between breaker crest and shoreline

[1] From Kwang K. Lee, "Longshore Currents and Sediment Transport in West Shores of Lake Michigan," Water Resources Research, Vol. 11, No. 6, December 1975.

[2] Computed from depths shown in Marina's Atlas, Lake Michigan, Gulf Publishing Co., 1988.

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Table 2-D-2
Maximum Predicted Mass Discharge
Waukegan Manufactured Gas & Coke Plant Site

Ratio Between Vertically Averaged Concentration and Deep Groundwater Concentration:							0.17	
	Ammonia (Kg/day)	Phenol (Kg/day)	Arsenic (Kg/day)	Average Ammonia Conc. (mg/l)	Ave. Phenol Conc. (mg/l)	Ave. Arsenic Conc. (mg/l)	Discharge of contaminated water (gpm)	Total Discharge of water (gpm)
To Slip No. 4	16.15	1.90	0.15	1,077.9	126.5	9.7	2.75	16.19
To Harbor (EG)	5.68	0.22	0.01	685.3	26.4	1.5	1.52	8.95
Total Harbor (AG)	25.57	4.26	0.19	993.3	165.5	7.4	4.73	27.82
To Lake Michigan (JK)	22.88	8.32	0.62	1,100.0	400.0	29.8	3.82	22.48
To Breakwater Area (HJ)	13.70	1.97	0.44	908.9	130.7	29.2	2.77	16.29
To Lake Side	36.58	10.29	1.06	1,019.7	286.8	29.5	6.59	38.77
Longshore Current Zone	50.91	13.62	1.10	826.2	221.0	17.9	11.32	66.59

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Table 2-D-3
Lake Michigan Surface Water Model
Near Shore Mixing Zone
To Lake Michigan (JK)
Waukegan Manufactured Gas & Coke Plant Site

Lake Michigan					
Ratio Between Vertically Averaged Concentration and Deep Groundwater Concentration:		0.17			
Scenario			Case 1	Case 2	Case 3
			Average flow	Low Flow	High Flow
Current velocity (m/s)			0.090	0.064	0.488
WCP site groundwater discharge, (m^3/day)	22.5	gpm	123	123	123
Lake segment inflows (m^3/day)			1,417,322	356,358	2,715,112
Lake segment outflows (m^3/day)			1,417,445	356,481	2,715,235
Dilution factor based on surface water and groundwater flows			11,570	2,911	22,163
Ratio between deep groundwater concentration and vertically averaged concentration			5.9	5.9	5.9
Ammonia concentration in mixing zone (ug/l)			16.14	64.2	8.43
Phenol concentration in mixing zone (ug/l)			5.870	23.34	3.064
Arsenic concentration in mixing zone (ug/l)			0.437	1.739	0.228

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Table 2-D-4
Lake Michigan Surface Water Model
Near Shore Mixing Zone
To Breakwater Area (HJ)
Waukegan Manufactured Gas & Coke Plant Site

Lake Michigan					
Ratio Between Vertically Averaged Concentration and Deep Groundwater Concentration:		0.17			
Scenario			Case 1	Case 2	Case 3
			Average flow	Low Flow	High Flow
Current velocity (m/s)			0.064	0.013	0.27
WCP site groundwater discharge, (m^3/day)	16.3	gpm	100	100	100
Lake segment inflows (m^3/day)			763,811	156,125	3,242,592
Lake segment outflows (m^3/day)			763,911	156,225	3,242,692
Dilution factor based on flow volume and average concentration			7,640	1,563	32,428
Ratio between deep groundwater concentration and vertically averaged concentration			5.9	5.9	5.9
Ammonia concentration in mixing zone (ug/l)			17.93	87.69	4.22
Phenol concentration in mixing zone (ug/l)			2.579	12.610	0.608
Arsenic concentration in mixing zone (ug/l)			0.576	2.816	0.136

Table 2-D-5
Waukegan Harbor Surface Water Model
Waukegan Manufactured Gas & Coke Plant Site

Waukegan Harbor				
Ratio Between Vertically Averaged Concentration and Deep Groundwater Concentration:	0.17			
Scenario		Case 1	Case 2	Case 3
Stormwater Inflows (m^3/yr)		432000	432000	432000
WCP site groundwater discharge, (m^3/day)	27.8 gpm	152	152	152
Lake inflows to Harbor (m^3/day)		57029	57029	57029
Reciprocal flows (m^3/day)		60479	184312	888871
Harbor outflow (m^3/day)		117509	241342	945900
Dilution factor based on surface water and groundwater flows		800	1600	6200
Ratio between deep groundwater concentration and vertically averaged concentration		5.9	5.9	5.9
Ammonia concentration in mixing zone (ug/l)		220	110	30
Phenol concentration in mixing zone (ug/l)		36	18	4.5
Arsenic concentration in mixing zone (ug/l)		1.6	0.79	0.20

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Table 2-D-6
Lake Michigan Surface Water Model
Longshore Current Zone
Waukegan Manufactured Gas & Coke Plant Site

Lake Michigan				
Ratio Between Vertically Averaged Concentration and Deep Groundwater Concentration: 0.17				
Scenario		Case 1	Case 2	Case 3
		Time-weighted average velocity	Velocities are less than this value 10 percent of the time	Velocities are greater than this value 10 percent of the time
Current velocity (m/s)		0.082	0.026	0.158
WCP site groundwater discharge, (m^3/day)	66.6 gpm	363	363	363
Lake segment inflows (m^3/day)		17,768,678	3,250,863	34,242,425
Lake segment outflows (m^3/day)		17,769,041	3,251,226	34,242,788
Dilution factor based on surface water and groundwater flows		49,000	9,000	94,000
Ratio between deep groundwater concentration and vertically averaged concentration		5.9	5.9	5.9
Ammonia concentration in mixing zone (ug/l)		2.87	15.7	1.49
Phenol concentration in mixing zone (ug/l)		0.767	4.19	0.398
Arsenic concentration in mixing zone (ug/l)		0.062	0.338	0.032

Table 2-D-7

Computed Surface Water Quality (Assuming Maximum Projected Groundwater Loading)

	Mixing Ratio	Surface Water Concentration[1]		
		Arsenic (µg/L)	Phenols (µg/L)	Ammonia (µg/L)
Lake Michigan Basin Water Quality Standards		148 chronic 340 acute	100	15,000[2]
Waukegan Harbor, Calculated Water Quality	High (6,200:1)	0.20	4.5	30
	Average (1,600:1)	0.79	18	110
	Low (800:1)	1.6	36	220
Breakwater Area, Calculated Water Quality	High (32,000:1)	0.14	0.61	4.2
	Average (7,600:1)	0.58	2.6	18
	Low (1,600:1)	2.8	13	88
Lake Michigan Open Waters Water Quality Standards		50	1	20
Lake Michigan East of Site, Calculated Water Quality	High (22,000:1)	0.23	3.1	8.4
	Average (12,000:1)	0.44	5.9	16
	Low (2,900:1)	1.7	23	64
Longshore Current Zone, Calculated Water Quality	High (90,000:1)	0.032	0.40	1.5
	Average (50,000:1)	0.062	0.77	2.9
	Low (9,000:1)	0.34	4.2	16
National Ambient Water Quality Criteria for the Protection of Aquatic Life	—	190 chronic	117 chronic	1,490 chronic
		360 acute	2,010 acute	2,600 acute

[1] The computed surface water concentrations are highly conservative because, in addition to using the peak groundwater mass flux, they do not account for natural attenuation mechanisms that remove mass, such as anaerobic biodegradation, aerobic biodegradation, adsorption, and chemical changes.

[2] In addition, un-ionized ammonia nitrogen must meet the following acute and chronic standards: April through October, acute 330 µg/L, chronic 57 µg/L; November through March, acute 140 µg/L, chronic 25 µg/L.

LAKE MICHIGAN

MILWAUKEE, WI.
(1958-1963)

CALM
2.6 %

10 %
5 %

WAUKEGAN, IL.
(1951-1964)

W

CALM
1.4 %

10 %
5 %

CHICAGO (O'HARE), IL.
(1953-1958)

CALM
6.4 %

10 %
5 %

N

Figure 2-D-1

AVERAGE ANNUAL WIND ROSES,
WAUKEGAN ILLINOIS AND VICINITY

ZION STATION UFSAR

Figure 2.3-2

AVERAGE ANNUAL WIND ROSES
MILWAUKEE, WAUKEGAN,
CHICAGO(O'HARE)
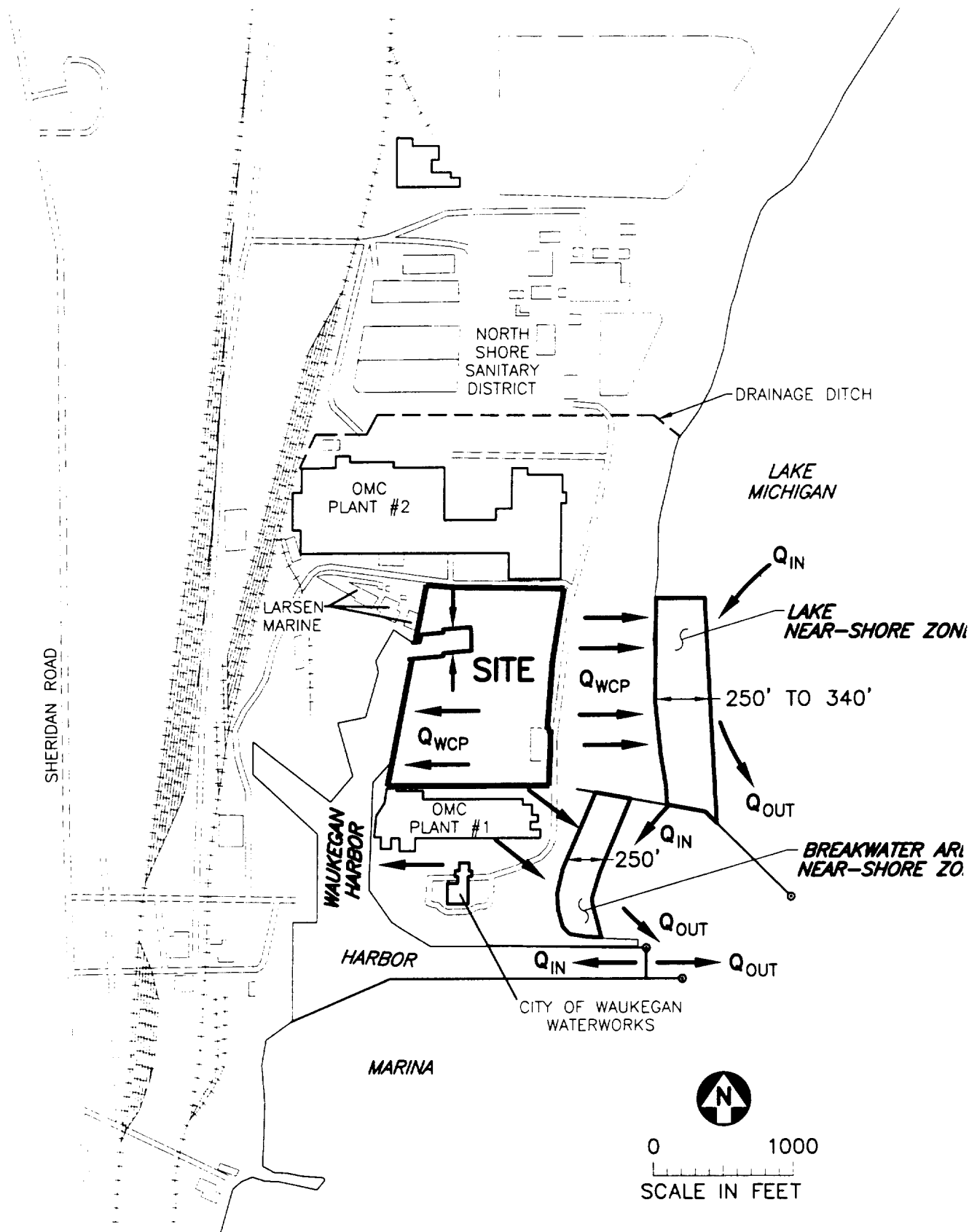
Figure 2-D-2
WAUKEGAN HARBOR AND LAKE MICHIGAN NEAR-SHORE ZONES
CONCEPTUAL SURFACE WATER MODEL
Waukegan Manufactured Gas & Coke Plant Site
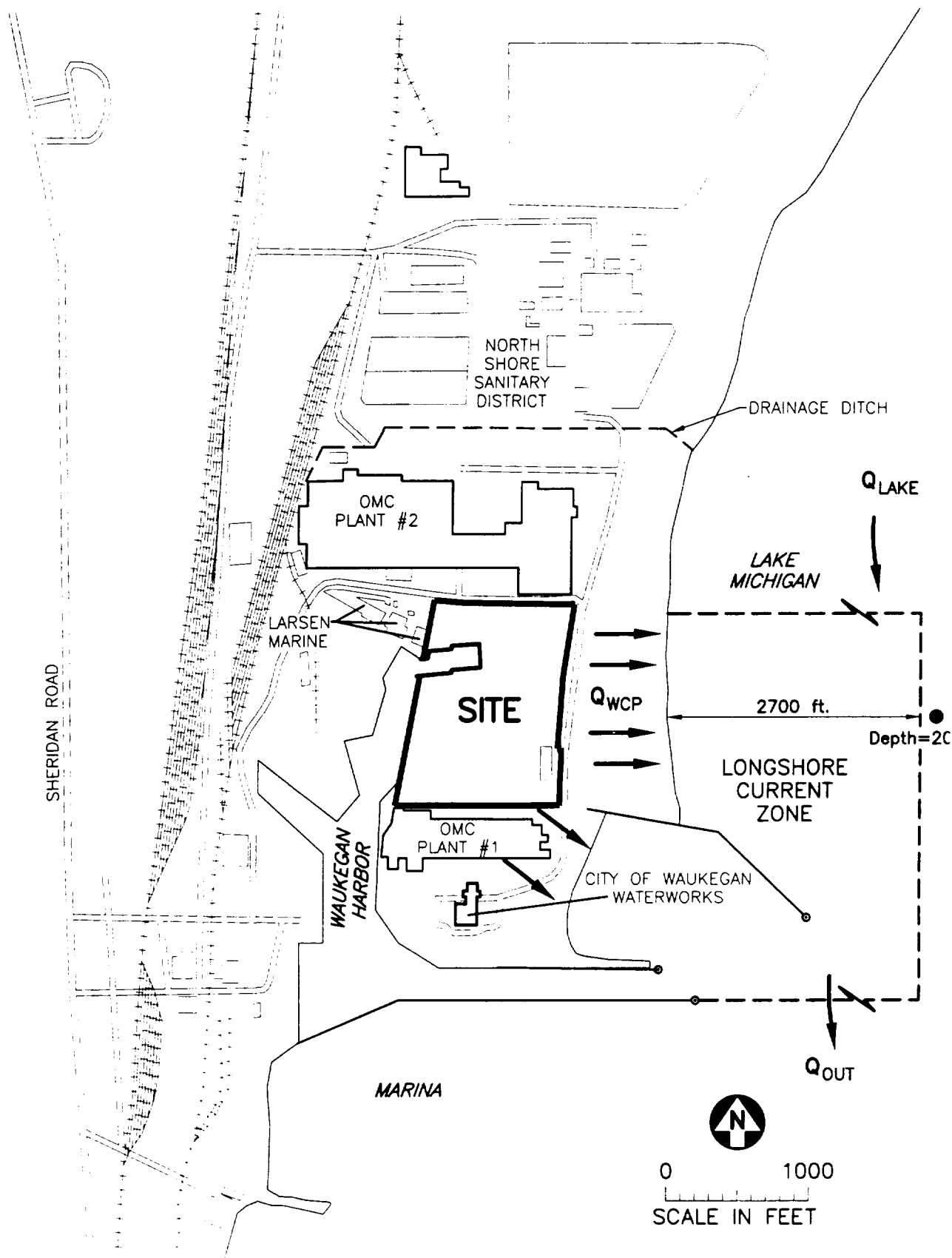
Figure 2-D-3
LAKE MICHIGAN CONCEPTUAL SURFACE WATER MODEL
Waukegan Manufactured Gas & Coke Plant Site

Lake Michigan Near Shore Currents
Argonne National Laboratory Data
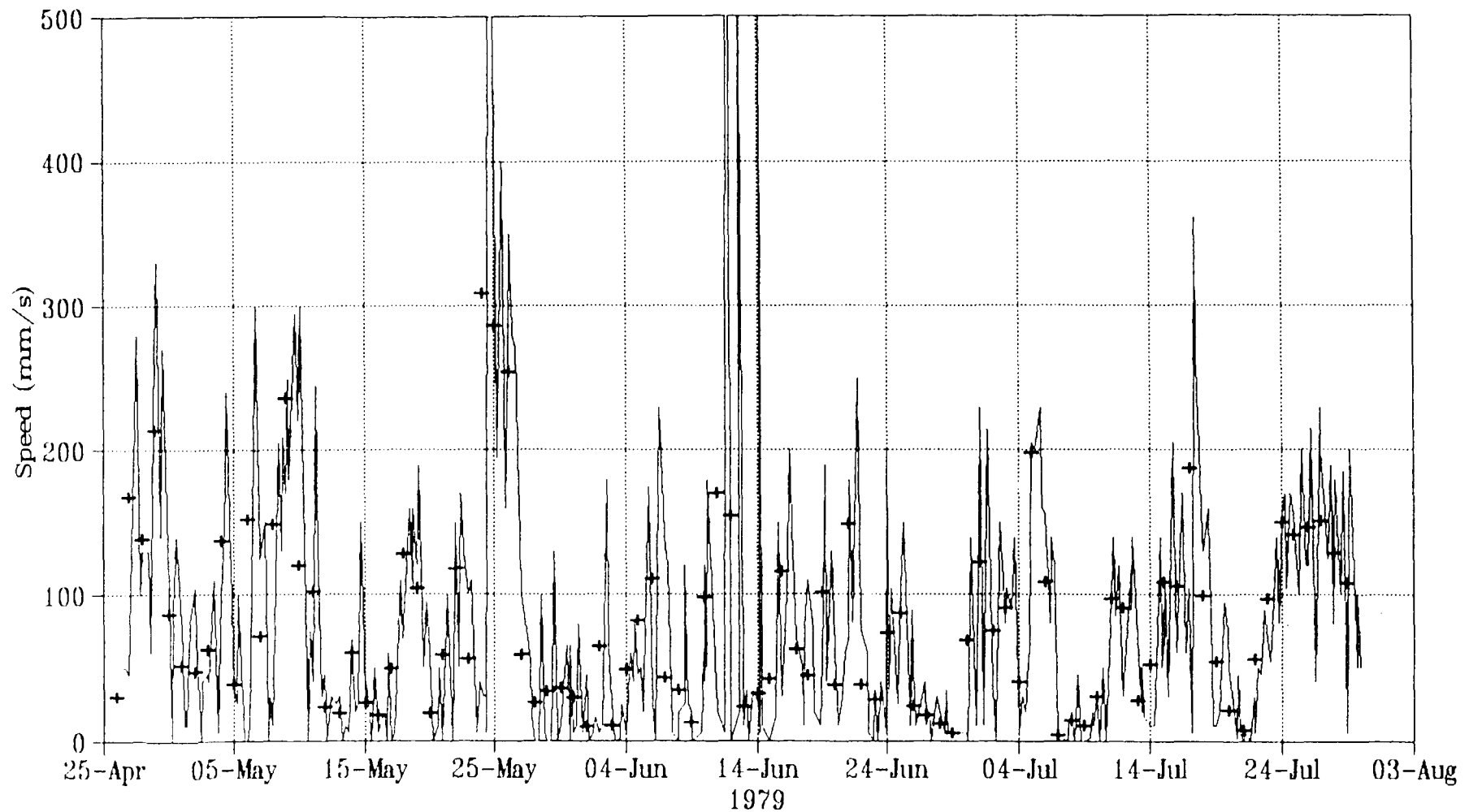
Legend: —— Measured Data + Average Daily

Lake Michigan Near Shore Currents
Argonne National Laboratory Data
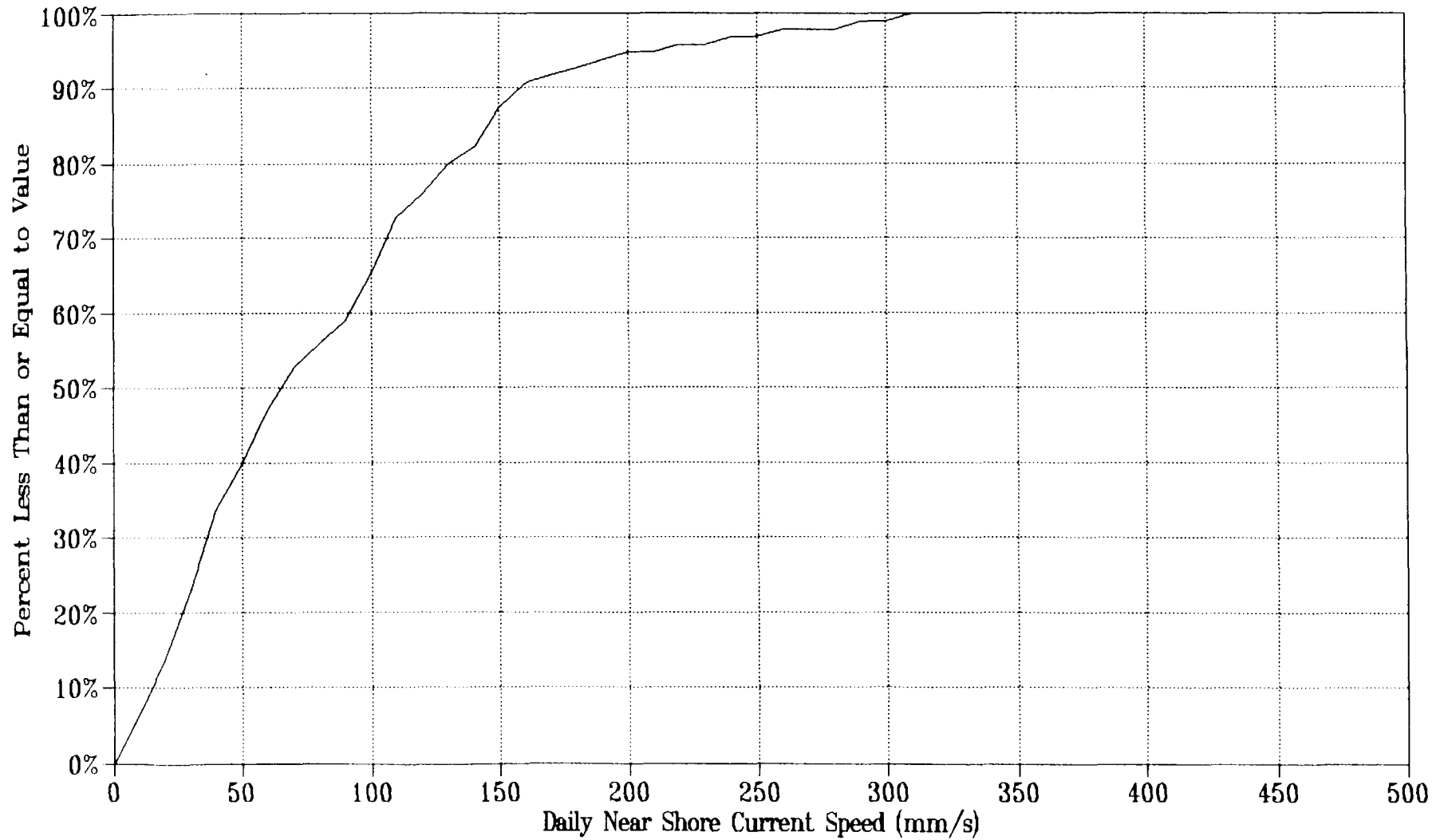
Daily Average

Figure 2-D-5

CURRENT VELOCITY
DISTRIBUTION
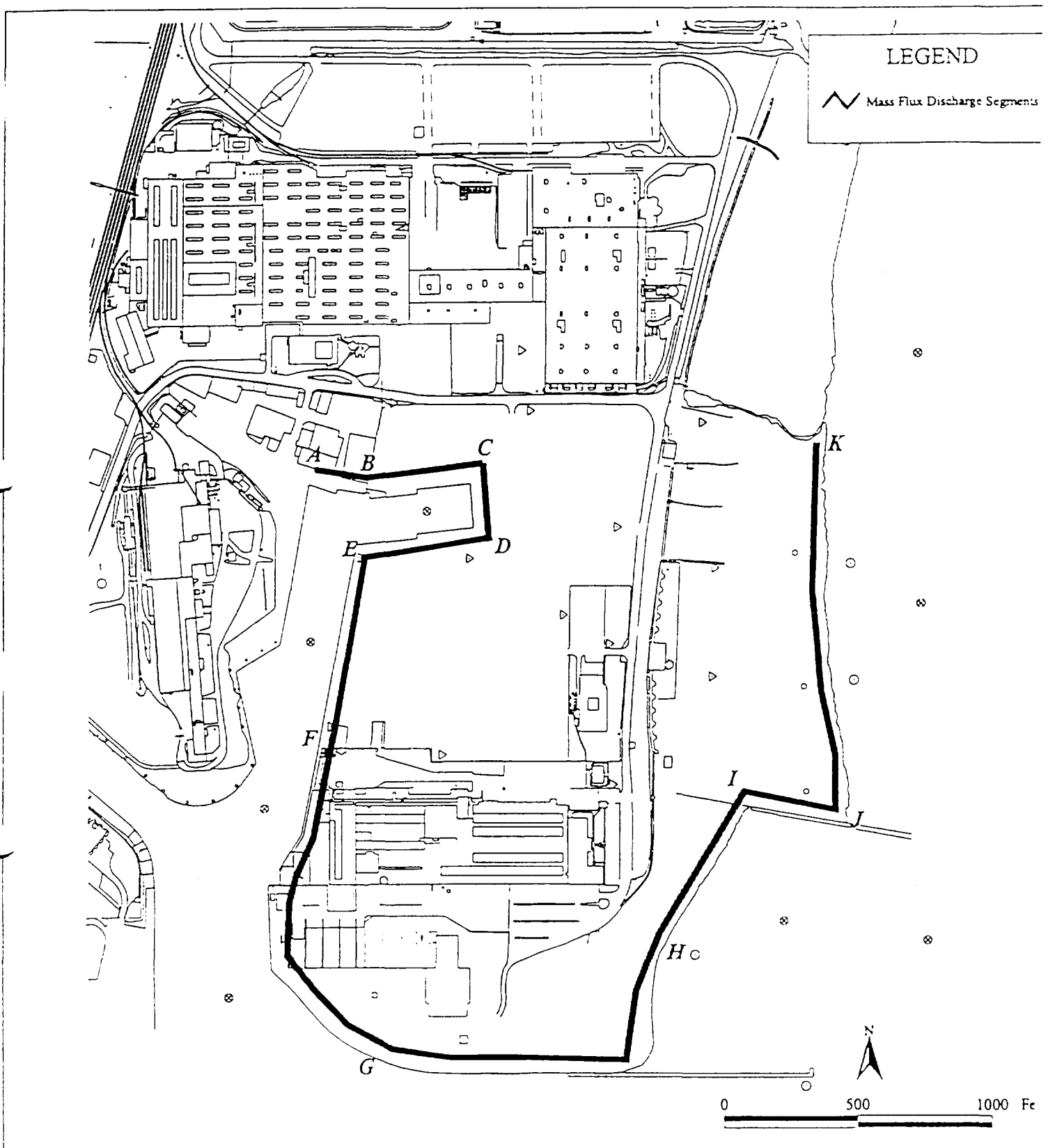
Figure 2-D-6

MASS FLUX DISCHARGE
SEGMENTS

Appendix 2-E

Boring Logs for
1997 Beach Investigations

Barr

DRILLING LOG

SHEET	1
OF	2 SHEET

PROJECT NAME/NO. WCP 13/49 - 003 JSL 276	SIZE AND TYPE OF BIT 4½ HSA
LOCATION (Coordinates or Season) SEE FIGURE	DATUM FOR ELEV. SHOWN MSL
DRILLING AGENCY BOART LONGYEAR	MANUFACTURERS DESIGNATION OF DRILL MOBLE 2.57 ATV
HOLE NO. SB - 61	TOTAL NO. OF OVER-BURDEN SAMPLES TAKEN ____ Disturbed ____ Undisturbed
NAME OF DRILLER MIKE MUELLER	TOTAL NO. CORE BOXES
DIRECTION OF HOLE ☒ Vertical ☐ Inclined ____ Deg. from Vert.	ELEV. GROUNDWATER 552.4
THICKNESS OF OVERBURDEN NA	DATE HOLE: 9/9/97 Started 9/9/97 Completed
DEPTH DRILLED INTO ROCK NA	ELEV. TOP OF HOLE 555.4
TOTAL DEPTH OF HOLE 33.5'	SIGNATURE OF INSPECTOR

SAMPLE	DEPTH	Soil PH	CLASSIFICATION OF MATERIALS (Description)	RECOV-ERY	N	REMARKS
SS	1	7.3	POORLY GRADED SAND (SP) FINE GRAINED PALE BROWN (10YR6/3) MOIST	10'	2	OVA READINGS 0/0/0 = 0
HP	2					W/O / W / W/O CARBON FILTER RESULT IS 1ST NUMBER MINUS 2ND NUMBER.
HP EXPOSED	3		(ALLUVIUM)			
	4		WET BELOW 3.0' 4.0' (581.4')			SB61W04
HSA	5		POORLY GRADED SAND (SP) FINE GRAINED GREY (5GY 6/0) WET			
	6					SEWER - LIKE ODOR BELOW 3 - FEET.
SS	7	7.5	W/ SMALL SHELL FRAGMENTS	16"	10	OVA 10/10/10 = 0
HP	8					
HP EXPOSED	9		(ALLUVIUM)			
	10		10.0' (575.4')			SB61W10
HSA	11		POORLY GRADED SAND (SP/SP-SM) FINE GRAINED GREY (5GY 6/0) WET			
	12					
SS	13	7.8		22"	11	OVA 15/8/6 = 7
HP	14		W/ SOME SHELL FRAGMENTS			
HP EXPOSED	15		(ALLUVIUM)			SB61W16
	16					
HSA	17					
SS	18	8.0		20"	15	OVA 175/75/70 = 100

Barr Engineering Company	DRILLING LOG	SHEET 2 OF 2 SHEET

PROJECT NAME/NO. WCP 13/49-003 JSL 276	SIZE AND TYPE OF BIT 4 1/2 HSA
LOCATION (Coordinates or Station)	DATUM FOR ELEV. SHOWN MSL
DRILLING AGENCY BOART LONGYEAR	MANUFACTURERS DESIGNATION OF DRILL B--
HOLE NO. SB – 61	TOTAL NO. OF OVER-SURDEN SAMPLES TAKEN ____ Disturbed ____ Undisturbe
NAME OF DRILLER MIKE MUELLER	TOTAL NO. CORE BOXES
DIRECTION OF HOLE ☒ Vertical ☐ Inclined ____ Deg. from Vert.	ELEV. GROUNDWATER
THICKNESS OF OVERBURDEN NA	DATE HOLE: 9/9/19 Started 9/9/19 Complete
DEPTH DRILLED INTO ROCK NA	ELEV. TOP OF HOLE 585.4
TOTAL DEPTH OF HOLE 33.5'	SIGNATURE OF INSPECTOR

SAMPLE	DEPTH	SOIL PH	CLASSIFICATION OF MATERIALS (Description)	RECOVERY	N	REMARKS
HP	21		SAME AS ABOVE SEE PAGE 1 for CLASSIFICATION.			
HP EXPOSED	22		22.5' (562.9)	SB61W22		
	23		POORLY GRADED SAND W/ SILT (SP-SM) FINE GRAINED DARK GREY (5GY4/0) WET (ALLUVIUM)			
ASA	24					
	25					OVA
SS	26	8.4		19"	14	600/175/175 = 425
	27					
HSA	28					
HP	29			SB61W30		
HP EXPOSED	30					2-FOOT / 2" SPLIT SPOON DRIVEN W/
	31					140 LB HAMMER 30-INCH DROP
HSA	32					W/ WINCH CABLES.
	33		TOP OF TILL @ 33.5± BASED ON TOOL ACTION			SB61,62,63,64
	34		33.5' END OF BORING (551.9')			
	35					SS = SPLIT SPOON
	16					HP = HYDRO PUNCH
	37					HSA = HOLLOW STEM AUGER
	33					SB61,62,63,64
	33					ODORS UNLESS DEFINED ARE PHENOLIC-LIKE SB-61,62,63,64

Barr	DRILLING LOG	SHEET 1 OF 2 SHEETS

PROJECT NAME/NO. WCP 13/49 - 003 JSL 276	SIZE AND TYPE OF BIT 4½ HSA
LOCATION (Coordinates or Station) SEE FIGURE	DATUM FOR ELEV. SHOWN MSL
DRILLING AGENCY BOART LONGYEAR	MANUFACTURERS DESIGNATION OF DRILL MOBLE B-57 ATV
HOLE NO. SB - 62	TOTAL NO. OF OVER-SURDEN SAMPLES TAKEN ___ Disturbed ___ Undisturbed
NAME OF DRILLER MIKE MUELLER	TOTAL NO. CORE BOXES
DIRECTION OF HOLE ☒ Vertical ☐ Inclined ___ Deg. from Ver.	ELEV. GROUNDWATER 582.9
THICKNESS OF OVERBURDEN NA	DATE HOLE: 9/12/97 Started 9/13/97 Completed
DEPTH DRILLED INTO ROCK NA	ELEV. TOP OF HOLE 584.4
TOTAL DEPTH OF HOLE 31.5'	SIGNATURE OF INSPECTOR

SAMPLE	DEPTH	SOIL PH	CLASSIFICATION OF MATERIALS (Description)	RECOV. ERY	N	REMARKS
HSA	1	7.8	POORLY GRADED SAND (SP) FINE GRAINED PALE BROWN (10YR 6/3) MOIST			OVA 0/0/0 = 0 NO ODOR
SS	3	7.8	W/ SMALL SHELL FRAGMENTS	15"	11	OVA 25/15/10 = 10 NO ODOR
HP	4		WET BELOW 1.5 - FEET			
HP EXPOSED	5-6		(ALLUVIUM) 6.0' (678.4')	SB62W06		
HSA	7-8		POORLY GRADED SAND W/ SILT (SP-SM / SP) FINE GRAINED GREY (10YR 5/1)			
SS	9	8.5	WET	24"	11	OVA 100/90/70 = 10 NO ODOR
HP	10-11		(ALLUVIUM)			
HP EXPOSED	12			SB62W12		
HSA	13-14					
SS	15	8.7		16"	35	OVA 10/5/5 = 2 NO ODOR
HP	16-17					
HP EXPOSED	18			SB62W18		

DRILLING LOG

Barr

HOLE NO. SB - 6

SHEET 2 OF 2 SHEETS

Field	Value
PROJECT NAME/NO.	WCP 13/49-003 JS2 276
LOCATION (Coordinates or Station)	
DRILLING AGENCY	BOART LONGYEAR
HOLE NO.	SB - 62
NAME OF DRILLER	MIKE MUELLER
DIRECTION OF HOLE	☒ Vertical ☐ Inclined ____ Deg. from Vert.
THICKNESS OF OVERBURDEN	NA
DEPTH DRILLED INTO ROCK	NA
TOTAL DEPTH OF HOLE	31.5'
SIZE AND TYPE OF BIT	4½ HSA
DATUM FOR ELEV. SHOWN	MSL
MANUFACTURERS DESIGNATION OF DRILL	B-5
TOTAL NO. OF OVER-BURDEN SAMPLES TAKEN	Disturbed ___ Undisturbed ___
TOTAL NO. CORE BOXES	
ELEV. GROUNDWATER	
DATE HOLE: 9/12/17 Started 9/15/17 Completed
ELEV. TOP OF HOLE	584.4
SIGNATURE OF INSPECTOR	D.M. M. Fr

SAMPLE	DEPTH	Soil PH	CLASSIFICATION OF MATERIALS (Description)	RECOV-ERY	N	REMARKS
SS	21	8.2	SAME AS ABOVE SEE PAGE 1 FOR CLASSIFICATION	15"	33	OVA 50/25/40 = 25
	22					SLIGHT ODOR
HP	23					
HP EXPOSED	24			SB6Z24		
HSA	25		24.5 (559.9') SILTY SAND (SM/SP-SM) FINE GRAINED DARK GREY (10YR 4/1)			
SS	26	8.5	WET (ALLUVIUM)	24"	17	OVA 100/200/200 = 200
	27					STRONG ODOR
HP	28					
HP EXPOSED	29			SB6Z30		
	30		TOP OF TILL 31.5± BASED ON TOOL ACTION			
HSA	31		31.5 END OF BORING (552.9')			
	32					
	33					
	34					
	35					
	36					
	37					
	38					

Barr	DRILLING LOG	SHEET 1 OF 2 SHEE

PROJECT NAME/NO. WCP 13/49-003 JSL 276	SIZE AND TYPE OF BIT 4½ HSA
LOCATION (Coordinates or Station) SEE FIGURE	DATUM FOR ELEV. SHOWN MSL
DRILLING AGENCY BOART LONGYEAR	MANUFACTURERS DESIGNATION OF DRILL MOBILE 2-57 AT
HOLE NO. SB-63	TOTAL NO. OF OVER-SURDEN SAMPLES TAKEN ____ Disturbed ____ Undisturb
NAME OF DRILLER MIKE MUELLER	TOTAL NO. CORE BOXES
DIRECTION OF HOLE ☒ Vertical ☐ Inclined ____ Deg. from Vert.	ELEV. GROUNDWATER 583.1
THICKNESS OF OVERBURDEN NA	DATE HOLE: 9/12/97 Started 9/12/97 Complete
DEPTH DRILLED INTO ROCK NA	ELEV. TOP OF HOLE 583.6
TOTAL DEPTH OF HOLE 31.5'	SIGNATURE OF INSPECTOR (signature)

SAMPLE	DEPTH	SOIL PH	CLASSIFICATION OF MATERIALS (Description)	RECOV. ERY	N	REMARKS
HSA	1		POORLY GRADED SAND (SP) FINE TO MEDIUM GRAINED			NO SOIL OVA OR PH Readings 0-2'
	2		PALE BROWN (10YR 6/3) MOIST			
SS	3	7.8		14"	5	OVA 20/15/10 = 2 NO ODOR
	4		WET BELOW 6"			
HP	5		(ALLUVIUM)			
HP EXPOSED	6			SB63W06		
	7					
HSA	8		W/ SMALL SHELL FRAGMENTS			
SS	9	8.3		24"	10	5/5/4 = 1 NO ODOR
	10					
HP						
HP EXPOSED	11 12			SB63W12		
	13					
HSA	14					
SS	15	8.0	15.0' (568.6)	20"	13	100/75/75 = 25 SLIGHT ODOR
	16		SILTY SAND (SM/SP-SM) FINE GRAINED			
HP	17		GREY (10YR 5/1) WET			
HP EXPOSED	18		(ALLUVIUM)	SB63W18		
	19					
HSA						

Barr

DRILLING LOG

HOLE NO. SB - 6

SHEET 2 OF 2 SHEET

Field	Value	Field	Value
PROJECT NAME NO.	WCP 13149-003 JSL 276	SIZE AND TYPE OF BIT	4 1/2 HSA
LOCATION (Coordinates or Station)		DATUM FOR ELEV. SHOWN	MSL
DRILLING AGENCY	BOART LONGYEAR	MANUFACTURERS DESIGNATION OF DRILL	B-5
HOLE NO.	SB - 63	TOTAL NO. OF OVER-BURDEN SAMPLES TAKEN Disturbed ___ Undisturbed	
NAME OF DRILLER	MIKE MUELLER	TOTAL NO. CORE BOXES	
DIRECTION OF HOLE ☒ Vertical ☐ Inclined ___ Deg. from Vert.		ELEV. GROUNDWATER	
THICKNESS OF OVERBURDEN	NA	DATE HOLE: 9/11/97 Started 9/11/97 Completed	
DEPTH DRILLED INTO ROCK	NA	ELEV. TOP OF HOLE	583.6
TOTAL DEPTH OF HOLE	31.5'	SIGNATURE OF INSPECTOR	

SAMPLE	DEPTH	Soil pH	CLASSIFICATION OF MATERIALS (Description)	RECOV. ERY	N	REMARKS
SS	21	8.0	SAME AS ABOVE SEE PAGE 1 FOR CLASSIFICATION	22"	13	OVA 75/50/00 = 25 ODOR
	22					
HP	23					
HP EXPOSED	24			585 w 24		
HSA	25					
	26					
SS	27	8.2		17"	13	OVA 130/30/25 = 100 STRONG ODOR
HP	28					
HP EXPOSED	29					
	30			585 w 30		
HSA	31		TOP OF TILL @ 31.5± BASED ON TOOL ACTION			
	32		END OF BORING 31.5 (552.1')			
	33					
	34					
	35					
	36					
	37					
	38					

| **Barr** Engineering Company | **DRILLING LOG** | SHEET 1 |
| | | OF 2 SHEET |

PROJECT NAME/NO. WCP 13/49-003 JSL 276	SIZE AND TYPE OF BIT 4½ HSA
LOCATION (Coordinates or Station) SEE FIGURE	DATUM FOR ELEV. SHOWN MSL
DRILLING AGENCY BOART LONGYEAR	MANUFACTURERS DESIGNATION OF DRILL MOBLE B-57 ATV
HOLE NO. SB-64	TOTAL NO. OF OVER- BURDEN SAMPLES TAKEN ___ Disturbed ___ Undisturbed
NAME OF DRILLER MIKE MUELLER	TOTAL NO. CORE BOXES
DIRECTION OF HOLE ☒ Vertical ☐ Inclined ___ Deg. from Vert.	ELEV. GROUNDWATER 583.9'
THICKNESS OF OVERBURDEN NA	DATE HOLE: 9/11/97 Started 9/12/97 Completed
DEPTH DRILLED INTO ROCK NA	ELEV. TOP OF HOLE 585.9
TOTAL DEPTH OF HOLE 327'	SIGNATURE OF INSPECTOR Order Mr Fox

SAMPLE	DEPTH	SOIL PH	CLASSIFICATION OF MATERIALS (Description)	RECOV-ERY	N	REMARKS
HSA	1	8.1	POORLY GRADED SAND (SP) FINE GRAINED PALE BROWN (10YR6/3) MOIST			OVA 0/0/0 = 0 NO ODOR
SS	3	8.2		12"	7	OVA 2/3/2 = 1 NO ODOR
HP			WET BELOW 2'			
HP EXPOSED	6		(ALLUVIUM)	SB64W6		
HSA	8					
SS	9	8.2		22"	11	OVA 0/0/0 = 0 NO ODOR
HP						
HP EXPOSED	12			SB64W12		
HSA						
SS	15	8.2		22"	12	OVA 9/5/6 = 4 NO ODOR
HP						
HP EXPOSED	18		18.0 (567.9') SEE DESCRIPTION ON PAGE 2	SB64W19		

Barr		DRILLING LOG		SHEET Z
				OF Z SHEETS

PROJECT NAME/NO. WCP 13/49-003 351 276		SIZE AND TYPE OF BIT 4½ HSA	
LOCATION (Coordinates or Station)		DATUM FOR ELEV. SHOWN MSL	
DRILLING AGENCY BOART LONGYEAR		MANUFACTURERS DESIGNATION OF DRILL B-5	
HOLE NO. SB - 64		TOTAL NO. OF OVER-SURDEN SAMPLES TAKEN: ____ Disturbed ____ Undisturbed	
NAME OF DRILLER MIKE MUELLER		TOTAL NO. CORE BOXES	
DIRECTION OF HOLE ☒ Vertical ☐ Inclined ____ Deg. from Vert.		ELEV. GROUNDWATER	
THICKNESS OF OVERBURDEN NA		DATE HOLE: 9/11/97 Started 9/12/97 Completed	
DEPTH DRILLED INTO ROCK NA		ELEV. TOP OF HOLE 585.9'	
TOTAL DEPTH OF HOLE 32.7'		SIGNATURE OF INSPECTOR [signature]	

SAMPLE	DEPTH	Soil PH	CLASSIFICATION OF MATERIALS (Description)	RECOV- ERY	N	REMARKS
SS	21	8.4	POORLY GRADED SAND W/ SILT (SP-SM/SP) FINE GRAINED	23"	9	OVA 45/15/25 =35 NO ODOR
H?	22		GREYISH - BROWN (10YR 5/2)			
HP EXPOSED	24		WET	SB64W24		
HSA	25		W/ SMALL SHELL FRAGMENTS			
SS	27	8.1	(ALLUVIUM)	24"	11	OVA 100/100/80 =0 SLIGHT ODOR
H?	28					
H? EXPOSED	30			SB64W30		
	31					
HSA	32		TILL @ 32.7' ± BASED ON TOOL ACTION			
	33		32.7' END OF BORING (553.2')			
	34					
	35					
	16					
	37					
	38					
	39					

Appendix 2-F

Potential Impact of
Anaerobic Processes on
Groundwater Contaminant Fate

Appendix 2-F.   Potential Impact of Anaerobic Processes on Groundwater Contaminant Fate along the Beach Transect of the Waukegan Manufactured Gas and Coke Plant Site

Introduction

The lower 5 feet of the 25 to 30 foot thick sand aquifer at the Waukegan Manufactured Gas and Coke Plant (WCP) site is contaminated with elevated concentrations of phenols, ammonia, thiocyanate, and arsenic. The deep groundwater chemically resembles the wastewater generated by coal conversion or coal gasification processes. Anaerobic biological treatment can treat coal conversion wastewater, and thus, should be able to treat the WCP site's deep groundwater. However, certain types of chemicals are not biodegraded under anaerobic conditions. For example, ammonia is not biodegradable under anaerobic conditions, but is biodegradable under aerobic conditions. Aerobic conditions exist in the shallow portion of the site's sandy aquifer. This appendix focuses on the anaerobic attenuation of groundwater contaminants found in the deep portion of the sandy aquifer.

A concern with the anaerobic biodegradation of phenol and other phenolic compounds is that their high concentrations inhibit anaerobic biological activity. Phenol is a self-inhibitory substrate, which means that higher concentrations of phenol result in slower rates of anaerobic biodegradation (Suidan et al., 1988; Sáez et al., 1991). If concentrations of inhibitory substrates are sufficiently high, then the microbial biomass will be subject to a net decay, and there will be no steady-state removal of the substrate (Gantzer, 1989). The reported upper limits of the phenol concentration capable of supporting anaerobic steady-state phenol biodegradation range from less than 100 mg/L (Sáez et al., 1991) to greater than 1000 mg/L (Suidan et al., 1988).

The presence of para-cresol, ortho-cresol, and ammonia can also inhibit the anaerobic biodegradation of phenol. Wang et al. (1988) reported that cresol concentrations of about 400 mg/L reduce the rate at which methanogenic bacteria degrade phenol by 50 percent. Blum et al. (1986) observed that para-cresol concentrations between 125 and 250 mg/L slow the anaerobic biodegradation of phenol by 50 percent. No inhibition of anaerobic phenol biodegradation was noticed in fluidized-bed GAC reactors when the sum of the ortho- and meta-cresol concentrations was less than 100 mg/L (Fox et al., 1988). Un-ionized ammonia-nitrogen concentrations greater than 55 mg N/L can cause the failure of methanogenic bioreactors (Bhattacharya and Parkin, 1989).

The above discussion indicates that the anaerobic biodegradation of the phenols found in the deep groundwater at the WCP site is possible provided that sufficient dilution is available to reduce the level of inhibition. There are several regions along the beach transect that could supply the appropriate electron acceptors (e.g., sulfate) and the degree of dilution required for the existence of anaerobic biologically active zones in the WCP aquifer. As illustrated in Figure 2-F-1, one potential location for an anaerobic biologically active zone is just above the highly contaminated region of the deep aquifer. Although the infiltration-dominated hydraulics of the groundwater has created a highly concentrated plume at the bottom of the aquifer, there is a diluted layer immediately above the contaminated layer. This dilution may be sufficient to support anaerobic biological activity. Sulfate diffusing upward from the plume and moving downward with the infiltrating groundwater is available to support sulfate-reducing bacteria. Other potentially capable anaerobic bacteria include various consortia of acid-formers and methanogens.

A second potential location for an anaerobic biologically active zone is beneath Lake Michigan. Phenol transport is retarded by adsorption on to aquifer solids, while sulfate is not

slowed by adsorption. The differential transport of sulfate and phenol could create regions of high sulfate concentrations and low phenol concentrations. The lower phenol concentrations could result in the growth of phenol-degrading anaerobic bacteria. The resulting anaerobic biodegradation of phenol would decrease the mass flux of phenol traveling toward Lake Michigan. An aerobic biologically active zone located above the anaerobic biologically active zone could result in further mass flux reductions.

The overall goal of this evaluation is to examine the potential impact of anaerobic biological processes on the fate of phenols in the deep groundwater of the WCP site. In particular, this study has the following two overall objectives:

1. Field data will be presented that indicate the existence of an anaerobic biologically active zone just above the WCP aquifer bottom; and

2. The potential reduction in phenol flux toward Lake Michigan due to the aquifer-bottom anaerobic biologically zone will be evaluated with mathematical modeling.

The aquifer-bottom anaerobic biologically zone is an intrinsic biological process. The ability of this biologically active zone to process phenols can be improved by reducing the concentration of phenols and/or the mass flux of phenols entering the biologically active zone.

Existence of the Aquifer-Bottom Anaerobic Biologically Active Zone

For this study, the beach transect is defined as a line running from monitoring well MW-13 directly eastward to the Lake Michigan shoreline. During September of 1997, four borings were placed along the beach transect using hydropunch sampling techniques. Groundwater samples were collected from each boring at about 6-foot intervals from the water table down to the till aquitard that defines the bottom of the sandy aquifer. The chemical analysis results were plotted in terms of the horizontal and vertical position of the sampling location using DeltaGraph™ (SPSS, Inc.), as presented later. The resulting contour graphs suggest the existence of an anaerobic biologically active zone.

Chloride and ammonia are regarded as conservative tracers in anaerobic environments. Both chemicals are not retarded by the sandy WCP aquifer. The source of the chloride and ammonia found in the deep portions of the aquifer is believed to be from aqueous discharges near the groundwater divide. Figure 2-F-2 illustrates the observed vertical concentration gradients that exist for chloride and ammonia above the till. Both plumes have developed a fringe that extends upward from the till to a thickness greater than 10 feet.

The concentration contour graph for sulfate is provided in Figure 2-F-3. The important observation is the existence of a "hole" in the sulfate contour graph at about 10-feet above the till. The analytical detection limit for sulfate was 2 mg $SO_4^=$/L, which makes the 1-mg/L contour below detection. This region of undetectable sulfate concentrations could be the result of sulfate-reducing bacteria using the sulfate as the terminal electron acceptor in the biodegradation of organic compounds traveling upward from the plume. The concentration contour graph for phenols (i.e., the total phenol concentration measured by the 4-AAP method) is provided in Figure 2-F-4 and also shows a concentration "hole" at about 10-feet above the till. The "hole" overlap suggests that sulfate-reducing bacteria are growing and consuming phenols.

Figure 2-F-4 also illustrates that the vertical concentration gradient for the phenols is compressed compared to the chloride and ammonia gradients. Concentrations of chloride and ammonia dropped by 99 percent over a vertical distance of 10 feet. In contrast, the phenols

concentration dropped by 99 percent over a distance of 5 feet. The difference in vertical concentration gradients between the phenols and chloride can be illustrated by plotting the ratio of the phenols concentration to the chloride concentration. As illustrated in Figure 2-F-5, the phenol to chloride ratio drops by a factor of 5 over the bottom 7.5 feet of the aquifer. The sharper phenols concentration gradient and the phenols concentration "hole" strongly suggest that the phenols are being anaerobically biodegraded just above the highly concentrated zone at the aquifer bottom. Retardation of the phenols by adsorption to aquifer solids could accentuate the gradient by slowing vertical transport.

The vertical concentration gradient for arsenic is also sharper than the chloride and ammonia concentration gradients. Figure 2-F-6 illustrates that the soluble arsenic to chloride ratio drops by a factor of 5 over the bottom 7.5 feet of the aquifer. Significant retardation of arsenic is unlikely in the WCP aquifer. This suggests that the compressed vertical concentration gradient for arsenic was created by some removal mechanism other than dilution.

A possible removal mechanism for soluble arsenic is related to the production of sulfides by the sulfate-reducing bacteria. Soluble arsenic in the presence of sulfide can produce As_2S_3, which is a stable precipitate (Battelle, 1995). Thus, the possible arsenic removal process has the following steps: (1) the dilution of the phenols and a lessening of inhibition, (2) when inhibition is sufficiently reduced, sulfate-reducing bacteria degrade the phenols and generate sulfide, and (3) the biologically-generated sulfide precipitates the arsenic.

In summary, the contour graphs for the September 1997 sampling of the beach transect suggest that an anaerobic biologically active zone exists above the concentrated plume. The absence of detectable sulfate and the low concentration of phenols above the plume suggest the presence of sulfate-reducing bacteria capable of biodegrading phenols. It is expected that the phenols can only be degraded after dilution.

Modeling Anaerobic Biodegradation along the Beach Transect

The contour graphs presented above suggest the presence of an anaerobic biologically active zone located above the contaminated plume at the bottom of the aquifer. The graphs suggest that at least one component of the anaerobic biologically active zone are sulfate-reducing bacteria. While the contour graphs suggest the existence of the anaerobic biologically active zone, they do not indicate the degree by which contaminant mass flux rates to Lake Michigan are reduced. Not all of the deepest geoprobe sample intervals were located immediately above the till. This precludes the calculation of mass flux rates, because the most highly-concentrated plume may not have been sampled. Mathematical modeling was used to estimate the potential reduction in mass flux of phenols to Lake Michigan due to the presence of the anaerobic biologically active zone.

A two-dimensional transport model with anaerobic biodegradation was used to predict the concentrations of phenols, sulfate, and sulfate-reducing bacteria along the beach transect. The two-dimensional transport model only considers the longitudinal (horizontal, or x-direction) velocity component of groundwater flow. With no vertical velocity component, the model represents all vertical transport in the aquifer as vertical dispersive mixing. Calibration of the transport model to the observed chloride concentration profile (Figure 2-F-2) indicated that the apparent vertical dispersivity along the beach transect is small. The calibrated model assumed that the ratio of the longitudinal to vertical dispersivities (α_x/α_z) is 1000, which is large compared to the α_x/α_z value of 100 often used in groundwater modeling (Frind and Germain, 1986). The small vertical dispersivity may reflect the downward advective influence of the infiltrating water.

The initial set of intrinsic biological rate constants yielded an S_{max} value for the phenols of 188 mg/L. S_{max} is derived from Haldane inhibition kinetics and represents the maximum steady-state concentration that will support a population of capable microorganisms. The predicted sulfate and phenols concentrations are provided in Figures 2-F-7 and 2-F-8, respectively. Figure 2-F-7 illustrates that the model predicted a sulfate concentration "hole" at a location similar to that observed in the field (Figure 2-F-3). The wedge shape of the predicted sulfate concentration "hole" is due to the model not considering the downward advective transport of sulfate-carrying infiltration water from the water table. Figure 2-F-8 illustrates that when the model included phenol biodegradation by the sulfate-reducing bacteria, the vertical concentration gradient for the phenols was sharpened. However, the predicted phenols gradient was not as great as that observed in the field. This suggests, along with the smaller than observed region of low sulfate concentrations, that kinetic coefficients resulting in higher S_{max} values (i.e., less inhibition) could better match the observed beach transect conditions.

Figure 2-F-9 provides the predicted distribution of sulfate-reducing bacteria for a S_{max} value equal to 188 mg/L of phenols. The predicted maximum bacterial concentrations are located around 5 feet above the till. The predicted region of reduced sulfate concentrations is located between 7.5-feet and 10.0-feet above the till. Thus, the modeling suggests that capable sulfate-reducing bacteria would be expected to occur just below the region of low sulfate concentrations.

The predicted reduction in the mass flux of phenols to Lake Michigan is 20 percent for the S_{max} value of 188 mg/l phenols. As shown in Figure 2-F-10, higher or lower S_{max} values than 188 mg/L will yield more or less phenol removal, respectively. However, decreasing the inhibition beyond the S_{max} value of 376 mg/L has little effect on the maximum predicted reduction in mass flux, 40 percent.

In summary, the two-dimensional transport model with anaerobic biodegradation was able to predict the observed region of low sulfate concentrations and the observed compression of the phenol concentration gradient. The modeling results suggest that the sulfate-reducing bacteria can reduce the mass flux of phenols to Lake Michigan by 20 percent, and that the reduction in mass flux could be as high as 40 percent.

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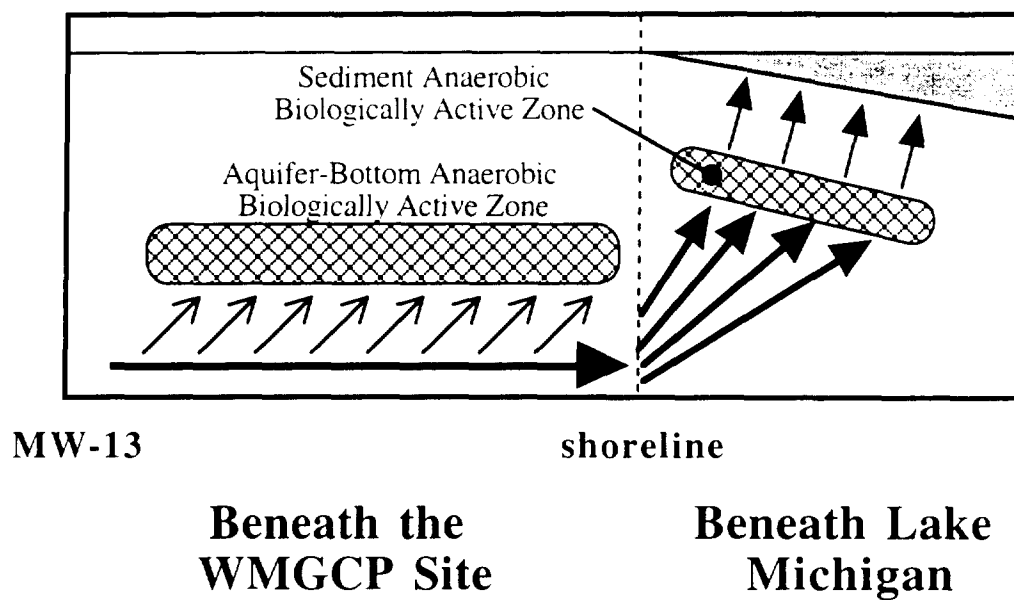
Figure 2-F-1. Schematic diagram showing the location of two potential anaerobic biologically active zones capable of biodegrading the phenols found in the deep portion of the WCP site aquifer. Potential aerobic biologically active zones exist above the two anaerobic biologically active zones. The diagram is not drawn to scale.
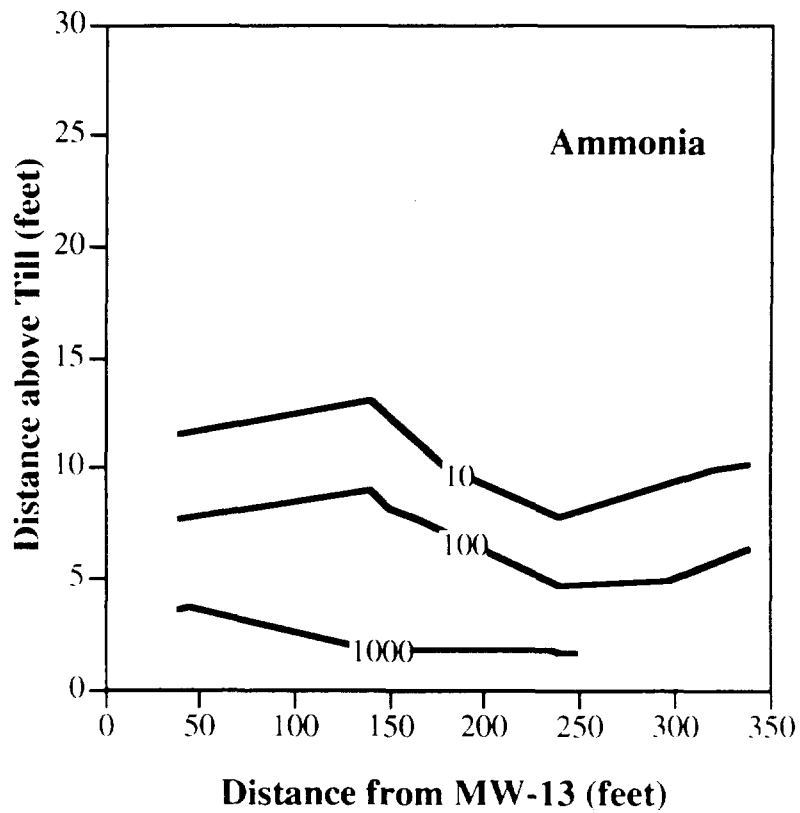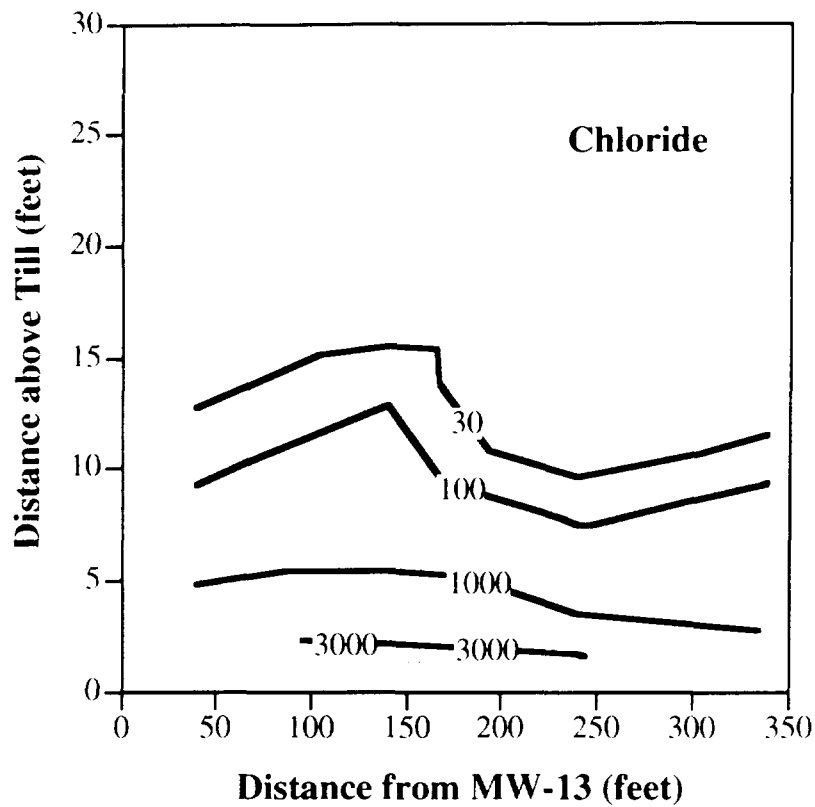
Figure 2-F-2. Chloride and ammonia concentrations along the beach transect. Both concentration profiles show an upward spreading of the respective plumes. Concentrations are expressed in mg/L for both chemicals.
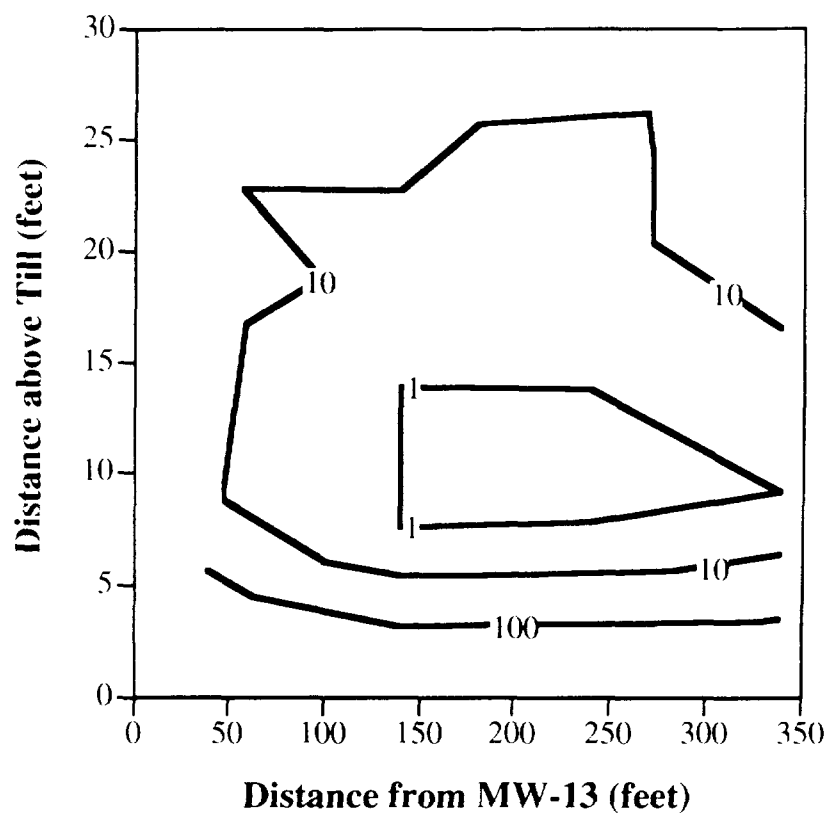
Figure 2-F-3. Sulfate concentrations (mg/L) along the beach transect. Note the sulfate concentration "hole" at 10-feet above the till.
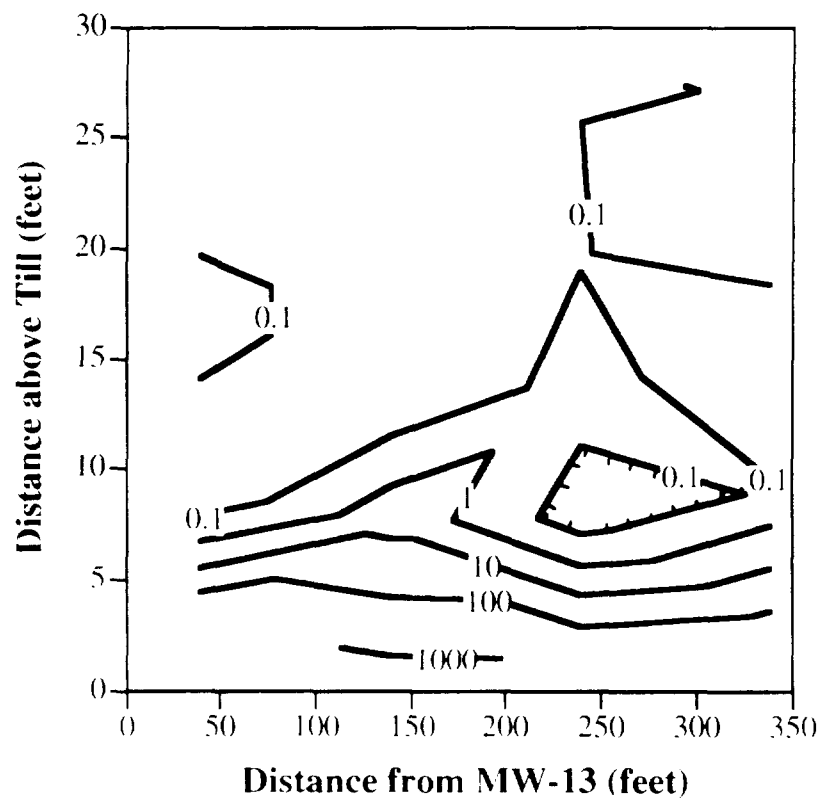
Figure 2-F-4. Concentration of phenols (mg/L) along the beach transect. Note the concentration "hole" at 10-feet above the till.
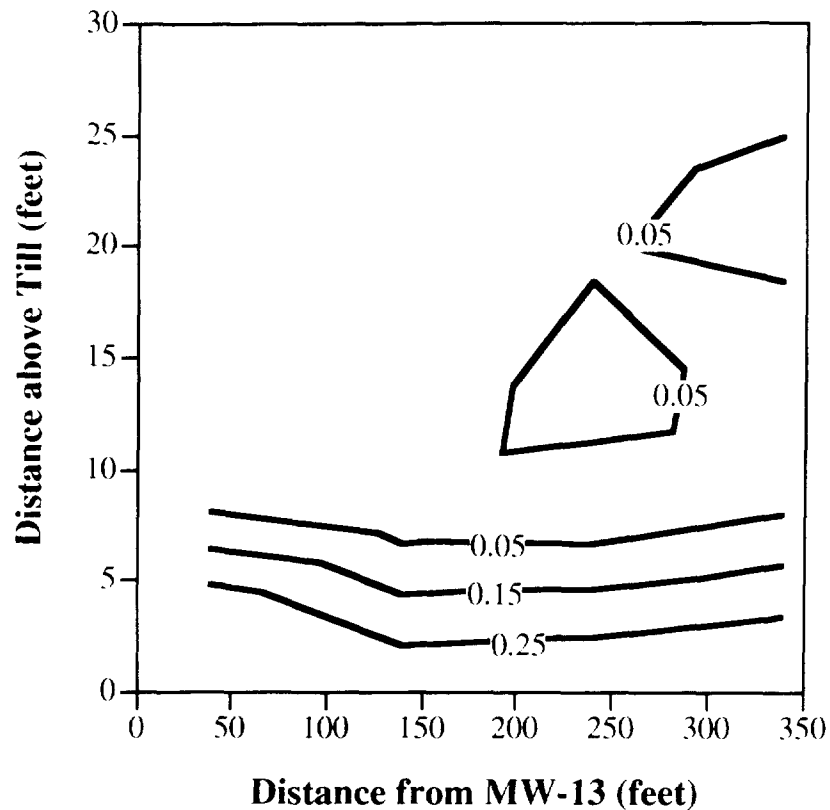
Figure 2-F-5. Ratios of the phenols concentration to the chloride concentration along the beach transect. The factor of 5 decrease in the ratio over the bottom 10 feet of the aquifer indicates that the vertical concentration gradient for the phenols is sharper than that for chloride, which suggests the existence of a possible phenol removal mechanism (*e.g.*, anaerobic biodegradation).

30 —

25 —

0.06   0.02   0.1

0.06

0.02

0.06

20 —

0.02

15 —

0.02

Distance above Till (feet)

10 —

0.02

0.06

5 —

0.1

0 —

0   50   100   150   200   250   300   350

Distance from MW-13 (feet)
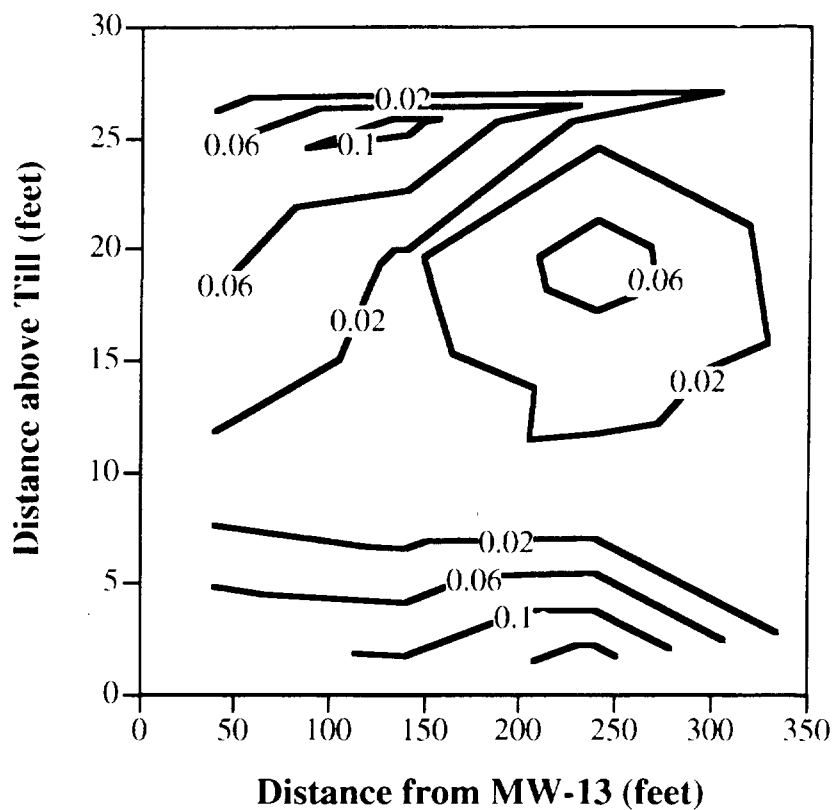
Figure 2-F-6. Ratios of the soluble arsenic concentration to the chloride concentration
 along the beach transect. The factor of 5 decrease in the ratio over the bottom 7.5 feet of
 the aquifer indicates that the vertical concentration gradient for the arsenic is sharper
 than that for chloride, suggesting the existence of a possible arsenic removal
 mechanism.
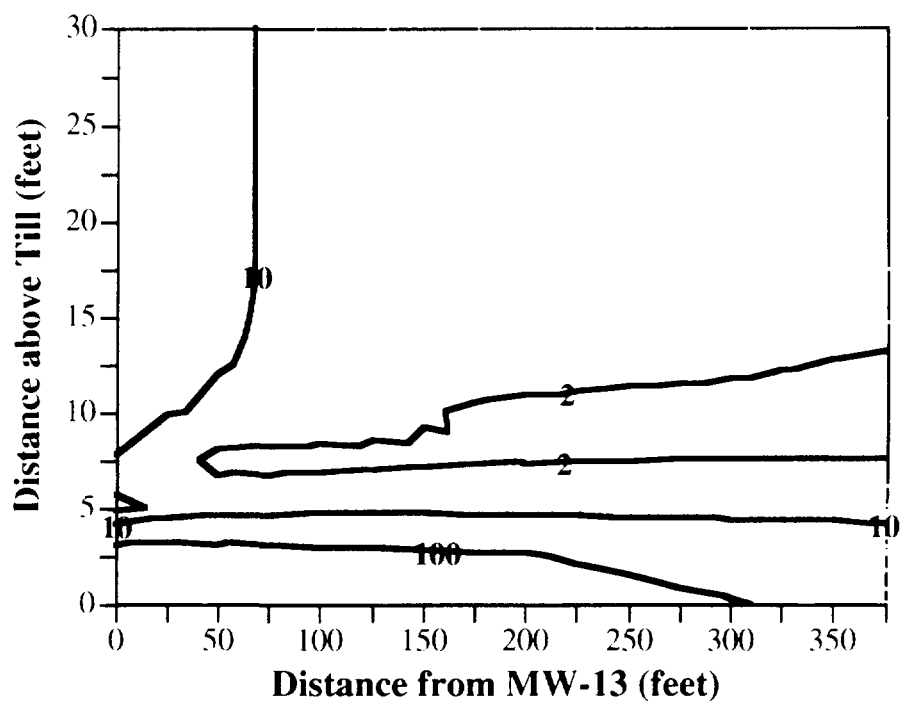
Figure 2-F-7. Predicted sulfate concentrations in mg/L for the beach transect with a phenols S$_{max}$ value of 188 mg/L. Note the sulfate concentration "hole" at about 10-feet above the till.
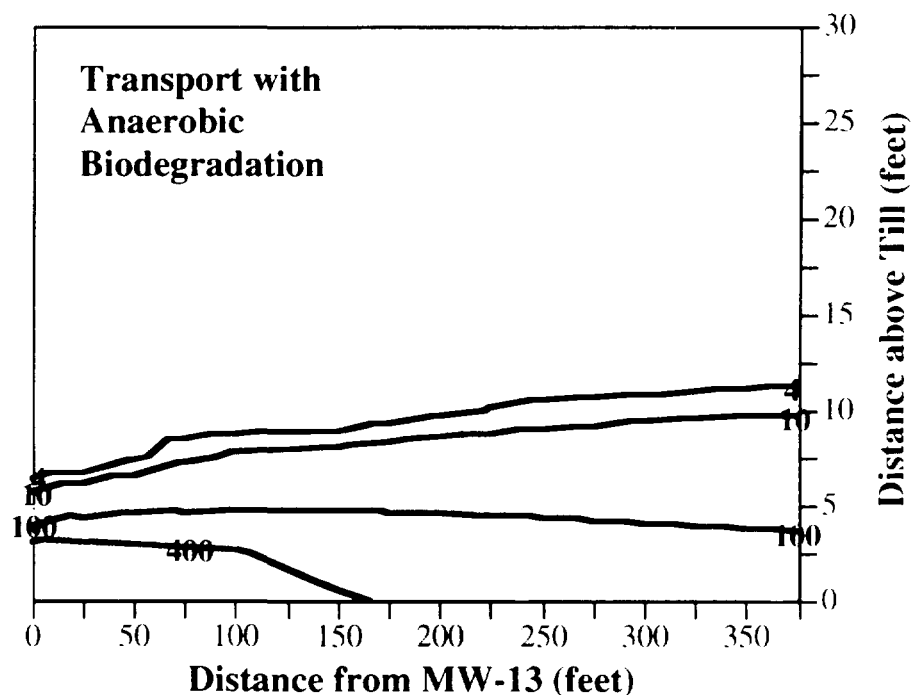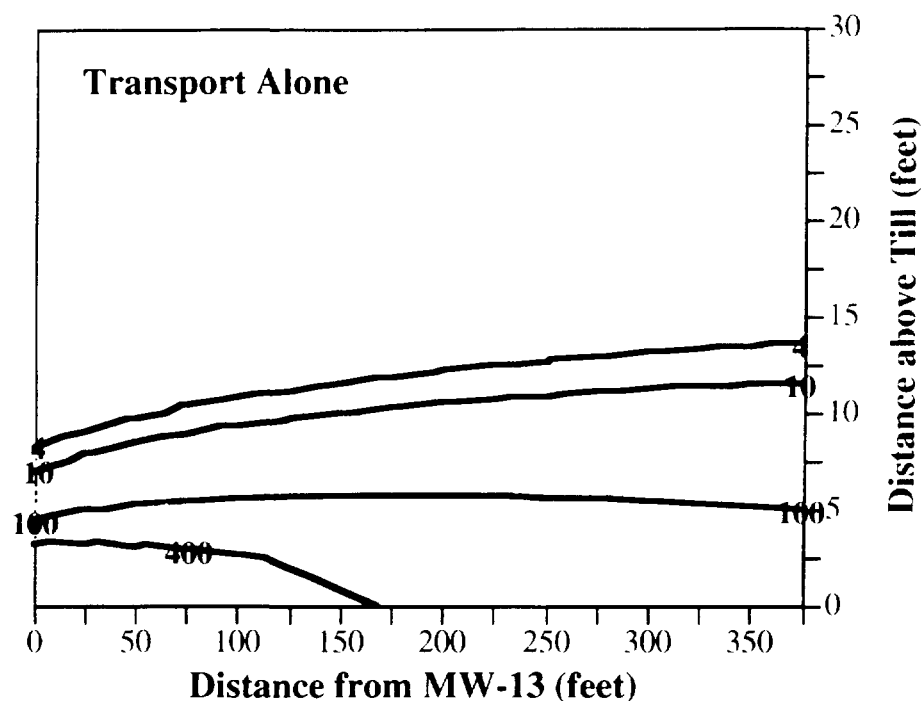
Figure 2-F-8. Comparison of the predicted phenols concentrations for transport alone and for transport with anaerobic biodegradation. Including the predicted activity of the sulfate-reducing bacteria (S_{max} = 188 mg/L) results in a steeper vertical concentration gradient.
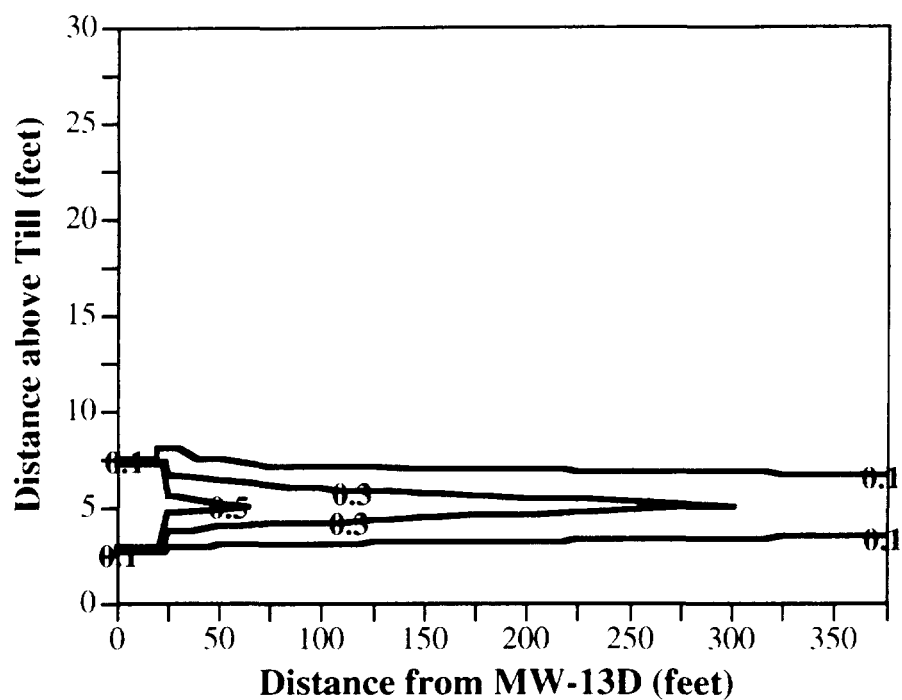
Figure 2-F-9. Predicted distribution of sulfate-reduction bacteria assuming a phenols S_{max} value of 188 mg/L. The contour lines are in mg/L.
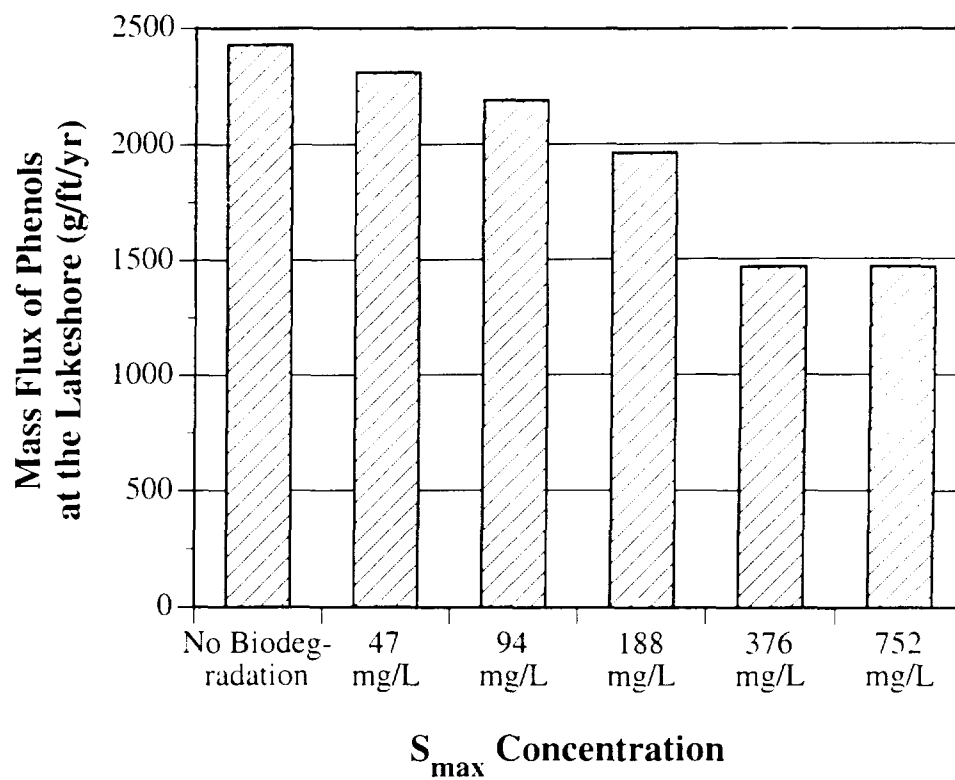
Figure 2-F-10. Predicted steady-state mass flux of phenols to the Lake Michigan shoreline as a function of biodegradability and degree of inhibition. The "No Biodegradation" simulation represents no biological activity or complete inhibition.

Appendix 2-G

Potential Impact of Aerobic Processes on Groundwater Contaminant Fate

Appendix 2-G.   Potential Impact of Aerobic Biological Processes on Groundwater Contaminant Fate in the Waukegan Manufactured Gas and Coke Plant Site Aquifer

Introduction

A continuous 25 to 30 foot thick sand aquifer exists beneath the Waukegan Manufactured Gas and Coke Plant (WCP) site. The aquifer has a 5-foot thick sand vadose zone above and a till aquitard below. The groundwater quality data contained in the Remedial Investigation (RI) Report and data subsequently collected in July/August 1996 and September 1997 indicate a vertically stratified distribution of contaminants in the aquifer. Groundwater samples indicate that the lower 5 feet of the aquifer is contaminated with elevated concentrations of phenols, ammonia, thiocyanate, and arsenic. The upper 20 feet of the aquifer only contains trace amounts of these compounds. As presented in Appendix 2-C, the hydraulic effects associated with the historical aqueous discharges near the groundwater divide and the advective transport by infiltration at the site once the plant was demolished and the site was graded can explain the stratification of the dissolved chemicals. However, groundwater hydraulics can not completely explain why the upper aquifer beneath the groundwater divide is free of organic compounds that are retarded by adsorption onto aquifer solids (e.g., phenol). Aerobic biodegradation of the residual organic compounds can help explain their absence in the upper aquifer. The aerobic biodegradation of phenol beneath the location of the groundwater divide is one instance where intrinsic aerobic biological processes are either remediating the WCP aquifer or reducing contaminant migration. This appendix focuses on the potential impact of aerobic biological processes on groundwater contaminant fate in the WCP aquifer.

The concentrations of phenols, ammonia, and thiocyanate found in the lower WCP aquifer resemble those found in wastewater generated by coal conversion or coal gasification processes. Aerobic biological treatment processes can treat coal conversion wastewater. A biotreatability study performed with WCP groundwater demonstrated the ability of aerobic microorganisms to biodegrade the phenols, ammonia, and thiocyanate found in the WCP site groundwater (Fluor Daniel GTI, 1998). However, successful aerobic biological treatment of the WCP groundwater collected from the bottom 5 feet of the aquifer required dilution to remove the inhibitory nature of the groundwater. Once the inhibition was removed, the biodegradation kinetics for each of the three compounds was consistent with previously published work examining the aerobic biological treatment of coal conversion wastewater. The biotreatability study also demonstrated the presence of phenol- and thiocyanate-degrading aerobic bacteria in the WCP site soil.

The ultimate sources of oxygen for aerobic biological activity in the WCP aquifer are atmospheric oxygen and the dissolved oxygen found in the Lake Michigan water column. The gaseous diffusion of oxygen through the air-filled pores of the vadose zone provides a greater oxygen flux to the aquifer than does oxygen delivery via infiltrating water. Air-equilibrated water at 12°C and infiltrating at about 1 ft/year provides an oxygen delivery rate to the aquifer of 0.01 g O_2/m^2/day. As shown in Figure 2-G-1, the predicted gaseous oxygen flux across the 5-foot thick vadose zone varies with the dissolved oxygen concentration at the water table. When the water table dissolved oxygen concentration is 10.5 mg/L (almost at saturation for 12°C water), the oxygen flux is 0.13 g O_2/m^2/day. The gaseous oxygen flux across the vadose zone is at least 13 times greater than oxygen delivery via the infiltration water. Any oxygen not consumed at the water table is transported deeper into the aquifer by advection. In this manner, atmospheric oxygen is available for the aerobic biodegradation of residual organic compounds found in the upper aquifer and of any biodegradable compounds migrating upward through the anaerobic

biologically active zone located 10-foot above the till. This anaerobic biologically active zone is described in Appendix 2-F.

The other source of oxygen for aerobic biodegradation is the dissolved oxygen found in the Lake Michigan water column. Mixing in the near-shore water column allows oxygen-saturated lake water to be in intimate contact with the sandy lake sediments. This mixing can provide up to 16 g O_2/m^2/day to the lake/sediment interface, based on an assumed effective diffusion layer thickness of 100 microns. A representative sediment oxygen demand for sandy sediments is 0.5 g O_2/m^2/day (Thomann, 1987). Thus, up to 15.5 g O_2/m^2/day is available for the aerobic biodegradation of compounds migrating toward the lake/sediment interface. This excess oxygen flux can meet the stoichiometric oxygen requirement for the biological oxidation of the phenol, thiocyanate, and 84 percent of the ammonia that could approach the lake/sediment interface, based on the hydraulics presented in Appendix 2-C. Thus, the aerobic biologically active zone located beneath the lake/sediment interface can have sufficient oxygen to biodegrade compounds that escape from the anaerobic biologically active zone located deeper in the lake sediments.

Evidence of Aerobic Biologically Active Zones

During September of 1997, groundwater samples were collected from four borings along the beach transect using hydropunch sample techniques. The beach transect is defined as a line running from monitoring well MW-13 directly eastward to the Lake Michigan shoreline. Groundwater samples were collected at about 6-foot intervals from the water table down to the till aquitard. The field-measured dissolved oxygen concentrations were used to develop Figure 2-G-2. The contour lines generated by the DeltaGraph™ (SPSS, Inc.) software indicate the absence of oxygen (*i.e.*, concentrations less than 0.1 mg/L) for significant portions of the aquifer. The closeness of the plotted oxygen depletion zone to the till suggests that the responsible aerobic biologically active zone (BAZ) is consuming compounds not entirely removed by the aquifer-bottom anaerobic BAZ.

Mathematical modeling was performed to estimate the location of the aquifer-bottom aerobic BAZ. The two-dimensional transport model described in Appendix 2-F was expanded to include both anaerobic and aerobic biodegradation of phenols. The kinetic coefficients used to describe the aerobic biodegradation of the phenols were obtained from the Biotreatability Study (Flour Daniel GTI, 1998). As illustrated in Figure 2-G-3, the predicted oxygen depletion zone has a similar extent to that observed in the field. The predicted oxygen depletion zone would be larger if the aerobic biodegradation of thiocyanate and ammonia were considered. The predicted distribution of aerobic phenol-degrading microorganisms is provided in Figure 2-G-4. The location of the modeled aerobic BAZ just above anaerobic BAZ suggests that the two BAZs are curtailing any upward migration of contaminants. It should be emphasized that the model only considers the horizontal advective transport of oxygen. By not considering the downward advective transport created by infiltration, the model is quite conservative in estimating oxygen delivery rates to the aerobic BAZ. Thus, the actual BAZ is probably functionally more important than indicated by the modeling.

In addition to the oxygen depletion zone or concentration "hole" located between 10 to 15 feet above the till, other evidence for aerobic BAZs at the WCP site includes the lack of detectable or significant water-phase concentrations of residual organic compounds in the upper aquifer at the groundwater divide. For example, the phenol concentrations in groundwater samples from monitoring well MW-7S have been less tnan 0.022 mg/L. These low observed concentrations suggest aerobic biological activity in the upper aquifer, because infiltration alone can not explain these low concentrations. Because monitoring well MW-7S is located at the

groundwater divide, there is no horizontal water flow. The only water available for flushing residual phenol is the infiltrating precipitation of 11.5 inches per year. If there were no aerobic activity, then detectable water-phase concentrations of phenol are expected, because infiltrating precipitation has been insufficient to flush all of the phenol out of this area.

Figure 2-G-5 illustrates the predicted water-phase phenol concentrations without biodegradation as a function of time since the aqueous discharges near the groundwater divide ceased. A retardation factor for phenol of 2.52 was assumed. The one-dimensional transport model suggests that water-phase phenol concentrations of about 45 mg/L should be measured in groundwater samples from monitoring well MW-7S after 30 years of flushing with 11.5-inches of infiltration per year. Because the observed concentration of 0.022 mg/L is much less than the predicted concentration of 45 mg/L, the field data and transport-alone modeling results suggest that additional phenol removal mechanisms beyond hydraulic flushing have reduced phenol concentrations in the upper aquifer at monitoring well MW-7S.

The one-dimensional transport model was expanded to consider the impact of aerobic biodegradation on water-phase phenol concentrations in the upper aquifer at monitoring well MW-7S. When aerobic biodegradation was considered, Figure 2-G-6 illustrates that the predicted water-phase concentrations in the upper aquifer are less than 0.0023 mg/L. Thus, one explanation for the low observed water-phase phenol concentrations at monitoring well MW-7S is aerobic biodegradation.

Summary

Biological processes have had and continue to have an impact on the fate of groundwater contaminants in the WCP aquifer. Appendix 2-F indicated that anaerobic biological processes can account for substantial mass flux reductions in contaminants traveling toward the Lake Michigan shoreline. This appendix provides evidence that aerobic biologically active zones also exist in the in the WCP aquifer. The physical setting of the aquifer can provide oxygen to the aerobic BAZs by gaseous diffusion across the vadose zone and by aqueous diffusion across the water/sediment interface beneath Lake Michigan. Modeling suggests that sufficient oxygen is available to account for the observed lack of phenol beneath the location of the groundwater divide. The size of the oxygen depletion zone along the beach transect indicates spatially large regions of aerobic biological activity. The combination of field data and modeling results suggest that aerobic microorganisms played an important role in cleansing of the upper aquifer and continue to prevent the upward migration of contaminants from the bottom 5 feet of the aquifer.

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Figures

Gaseous Oxygen Flux Across the Vadose Zone $(g/m^2 \cdot day)$ vs. Dissolved Oxygen Concentration at the Water Table (g/m^3)

Distance above Till (feet)

Distance from MW-13D (feet)

0.1

0.1

0.1

0.1

Phenol Concentration (mg/L)

Depth into Aquifer (feet)

Legend:
- 1 year
- 5 years
- 10 years
- 30 years
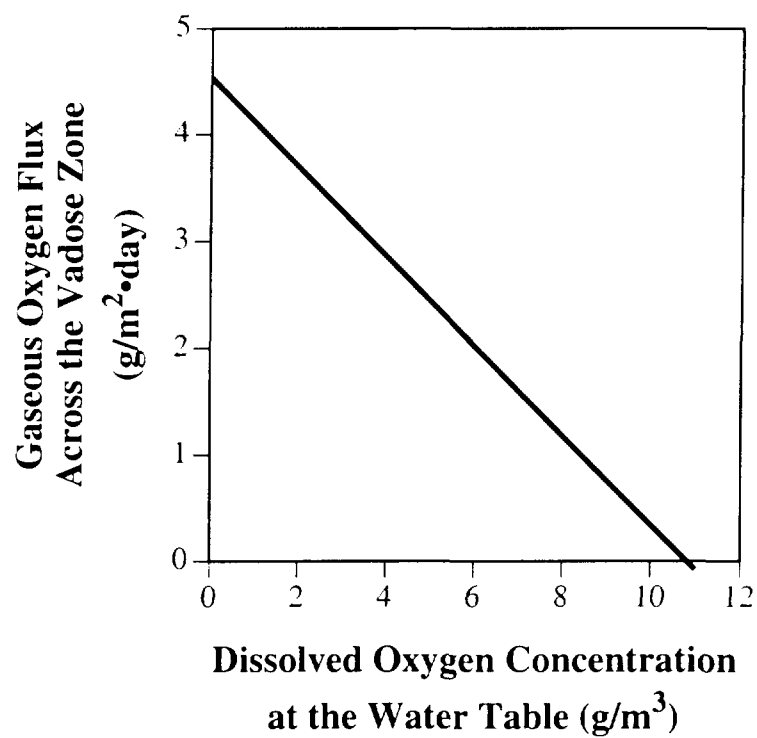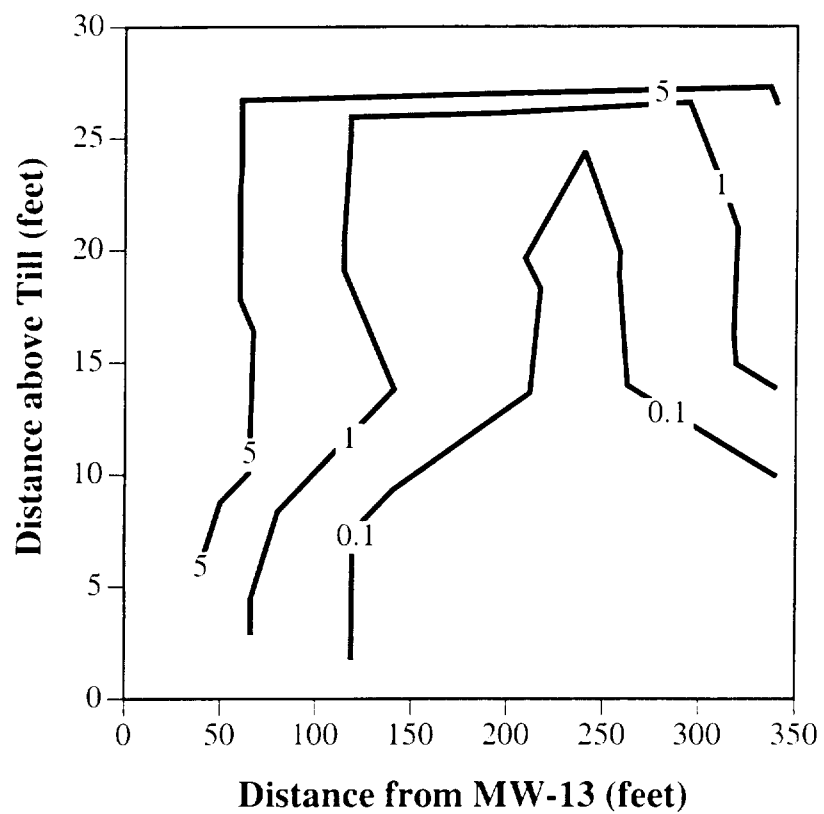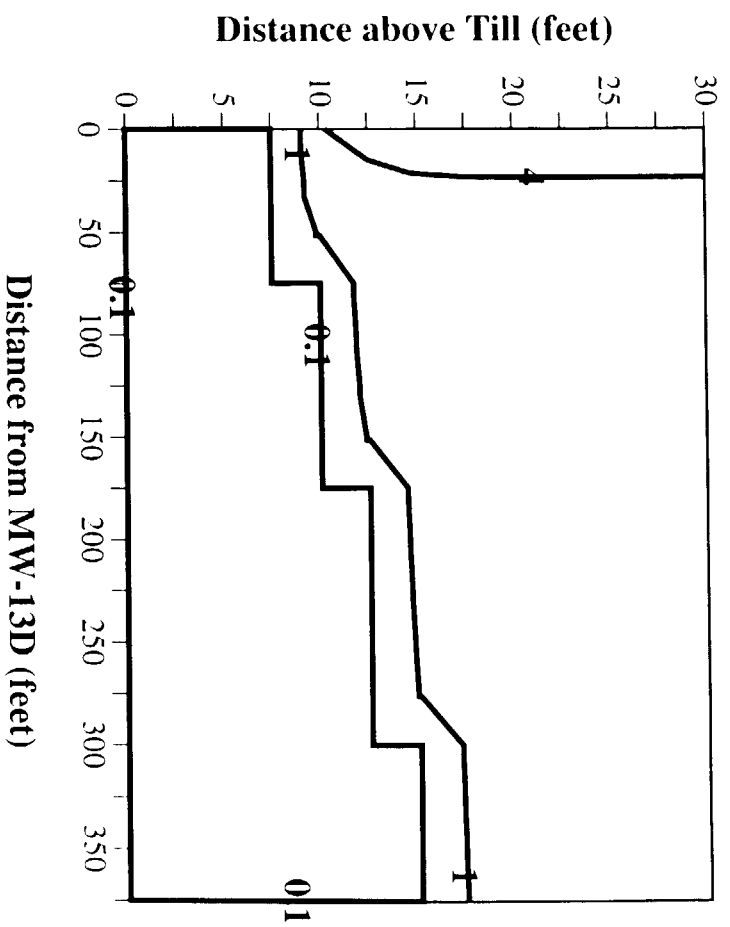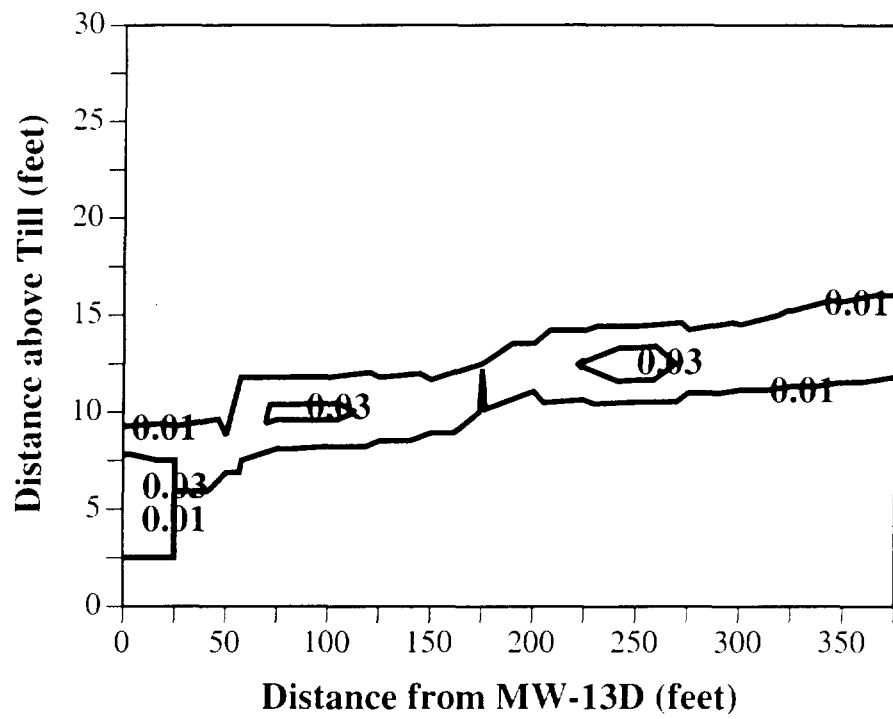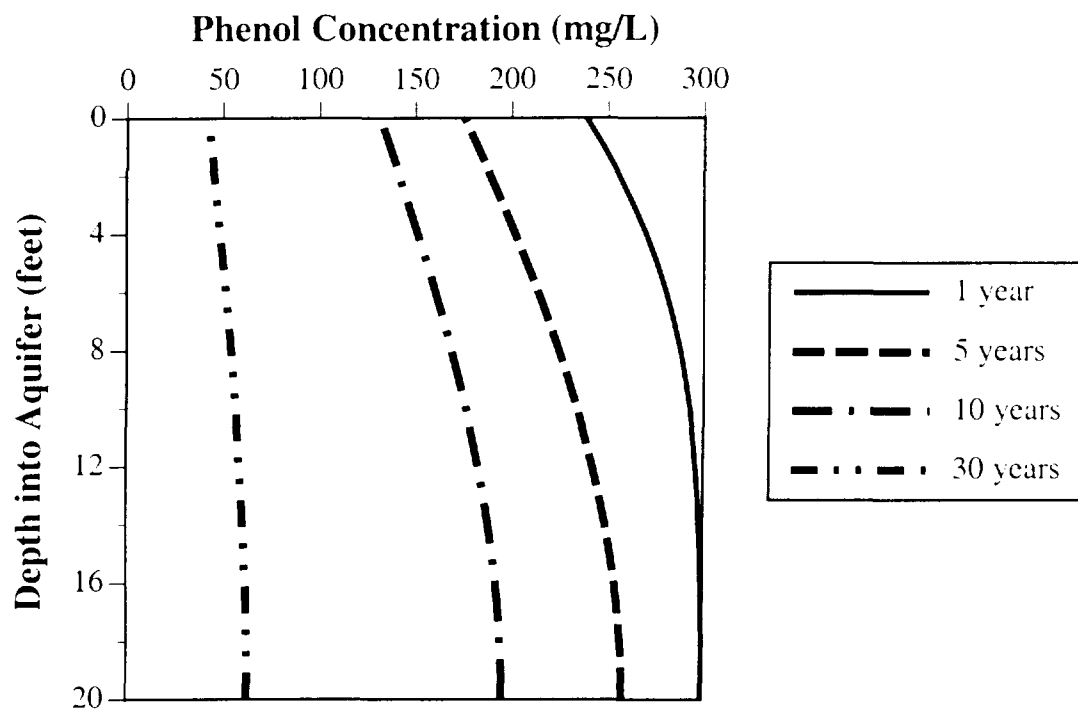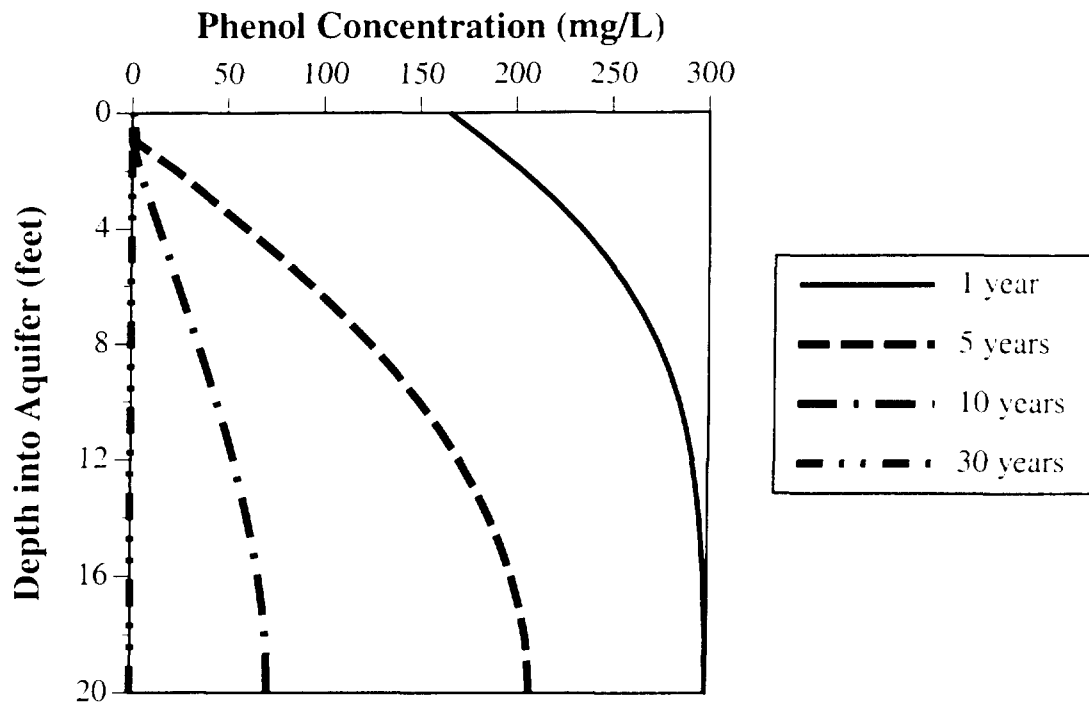
Appendix 3-A

Future Land
Use Considerations

Appendix 3-A

Future Land Use Considerations

This appendix follows the CERCLA guidance document, *Land Use in the CERCLA Remedy Selection Process, OSWER Directive No. 9355.7-04*, dated May 25, 1995, in assessing the appropriate future land uses for consideration of remedial alternatives for the site.

As stated in *Land Use in the CERCLA Remedy Selection Process* (U.S. EPA., 1995d), "remedial action objectives developed during the RI/FS should reflect the reasonably anticipated future land use or uses."

The guidance lists sources and types of information that may aid the U.S. EPA in determining the reasonably anticipated future land use. Those potentially applicable to the WCP site are as follows:

- Current land use

- Zoning laws

- Comprehensive community master plans

- Population growth patterns and projections (e.g., Bureau of Census projections)

- Accessibility of site to existing infrastructure (e.g., transportation and public utilities)

- Institutional controls currently in place

- Site location in relation to urban, residential, commercial, industrial, agricultural and recreational areas

- Historical or recent development patterns

- Natural resources information

- Potential vulnerability of groundwater to contaminants that might migrate from soil

- Proximity of site to critical habitats of endangered or threatened species

- Geographic and geologic information

Information from these sources, gathered during the RI/FS work, is briefly summarized or referenced in the sections below. Several of the categories are combined for the sake of brevity.

Current Land Use

OMC and Larsen Marine are the current owners and tenants at the site. Most of the site is vacant land. However, there are buried foundations and debris in many areas, left over from OMC's demolition of the former coke plant in about 1972. The portion of the property occupied by OMC is used for industrial purposes, including office space and parking. Larsen Marine uses the property to store boats and has an option to purchase large portions of the property.

OMC has industrial operations, parking, and offices on a small portion of the southeast corner of the site and manufacturing operations adjacent to the site, on the south at OMC Plant No. 1 and on the north at OMC Plant No. 2. The OMC office building (the old office building from the manufactured gas and coke plant) and the OMC "data" building just north of the OMC office building are located on the southeast corner of the site, as shown on Figure 2-1 (Section 2). The southeast corner of the site is the only portion of the site in active use by OMC. This area is covered by lawn, parking lots, buildings, and landscaping. Subsurface work, such as repair of subsurface installations (i.e., utilities and sprinkler systems), has occurred on occasion in this limited area, but not every year. Subsurface and utility work is not normally performed in the inactive portion of the site.

The land currently occupied at the site by Larsen Marine is located at the northwest corner of the site. The Larsen operations at the site are service and storage of boats, and operations at the boat slip. Nearly all the land that Larsen Marine controls is covered with buildings, pavement, or gravel. Areas without a cover material are found east and south of Slip No. 4 or in Larsen's outer fenced area that Larsen uses for storage of boat trailers and cradles and wintering of boats.

OMC and Larsen Marine have expressed intentions to expand operations similar to their current activities onto the site in the future. Larsen Marine has a legal right to expand their operations onto large portions of the site, and is expected to develop the property consistent with their existing facility. It is also reasonable to expect that future OMC expansion on the WCP property will be similar to the current OMC land use at and adjacent to the property.

The anticipated future land use by current owners and tenants is commercial and industrial.

Zoning Laws and Maps

The zoning at and around the WCP site is shown on Figure 2.2-1 of the RI report. The City of Waukegan zoning ordinance and map shows the northern portion of the WCP site, at and adjacent to Larsen Marine, for marine/commercial recreation use. This zoning category is for commercial operations that support the recreational marine market. The same zoning applies across the harbor southwest of the site.

The southern portion of the site is zoned general industrial, as is the area north of the site and west of the harbor. This zoning category is for industrial use, as typified by OMC's operations and National Gypsum's facility west of the harbor.

South of OMC Plant No. 1 and east of Sea Horse Drive, the zoning is conservation/recreation, and includes the public beach and the city waterworks.

Comprehensive Community Master Plans

The Waukegan comprehensive land use plan, adopted on June 6, 1988, shows the planned future use for the site is industrial. The beach is classified as recreational open space, and the waterworks is mapped as public/semi-public future land use.

Population Growth Patterns, Accessibility of Site to Existing Infrastructure, and Historical or Recent Development Patterns

The 1980 population of the City of Waukegan was 67,653, and the 1990 population was 69,392, an increase of 2.6 percent from 1980. The site has access to the harbor and is well served by utilities and roads. The Waukegan waterfront has historically been industrial land. Patterns of growth in Waukegan have not put residential development pressure on the lakefront. Rather, marine/ commercial recreational development has expanded in the area. The construction of New South Harbor and the Port Authority facility has added nearly 1,000 boat slips to Waukegan, increasing the pressure to expand support functions such as those contemplated in the marine/commercial recreation zoning category.

Institutional Controls Currently in Place

The Waukegan Harbor Superfund site, which encompasses the WCP site, is the location of hazardous waste land units operating under TSCA authorizations. As a condition of the Consent Decree for the Superfund site, OMC may not transfer the subject property, including the WCP site,

without prior notice to the U.S. EPA. The OMC Consent Decree also requires that notice of the site restrictions be provided to prospective purchasers. Land use restrictions are expected to be imposed, or if not, additional analysis of residential scenarios may be needed.

Site Location in Relation to Urban, Residential, Commercial, Industrial, Agricultural and Recreational Areas

The presence of three hazardous waste containment cells for PCBs on OMC and former Larsen Marine property in the vicinity of the site is consistent with the industrial character of the current and anticipated future land use. As noted in the discussion of zoning above, the site is surrounded on the north, west, and south by commercial and industrial land and a harbor. To the east lies Waukegan Beach, a city open space/park/recreational area. Portions of the site have been used in the past for overflow parking during major events at Waukegan Beach.

The lakefront area is cut off from the commercial and residential centers of Waukegan by the Amstutz Expressway. East of the expressway (on the Waukegan Harbor side), the area is dominated by land uses that are industrial (including railroad), commercial marine, and public.

Natural Resources Information, Groundwater Vulnerability, Critical Habitats, and Geographic and Geologic Information

The ecological considerations for the site and vicinity are presented in the RI report. Other information related to geology, groundwater conditions, and contaminants is presented in detail elsewhere in the RI and FS.

An important consideration is the use of surface water adjacent to the peninsula, which includes fishing at Waukegan Harbor and Lake Michigan and swimming in Lake Michigan. The harbor serves commercial shipping, including raw materials delivery to National Gypsum, cement delivery, and barge and tug mooring. The harbor provides access to maintenance facilities for recreational boating, and has marina facilities. Lake Michigan serves the commercial shipping industry, commercial and recreational users, and the businesses and communities around the lake. Future uses of the lake and harbor are expected to be consistent with current use.

Groundwater Use

No known drinking water wells exist onsite or in the immediate vicinity of the Waukegan Harbor peninsula. The site groundwater is not currently used for any water supply. Furthermore:

- City water is available at Sea Horse Drive.

- The Waukegan zoning code prohibits wells in new residential developments where city water is available.

- Waukegan restricts the installation of industrial wells.

- The City of Waukegan is expected to adopt an ordinance specifically prohibiting the placement of residential water supply wells within the city limits.

- The contamination present in the site groundwater precludes authorization of drinking water wells at the site in the future because the state well code requires a permit for well installation, and the Health Department denies permits when it is known that contamination exists.

- The county has adopted the Health Department guidelines. In addition, the county also prohibits installation of wells within a certain distance of contaminated areas.

These constraints prohibit placement of individual water wells.

Conclusion from Land Use Review

From this review, it is clear that the past land use at the WCP site has been industrial and commercial. The current use for the property is industrial and commercial. Planned future use of the property would most likely be industrial or commercial. Residential use is neither a past, present, nor likely intended future use of the site and would be inconsistent with the current industrial and commercial uses such as the PCB disposal cells adjacent to the site. Land use restrictions are expected to be imposed, or if not, additional analysis of residential land use scenarios may be needed. Industrial and commercial land use is consistent with the surrounding land uses. Adjacent land use is open space, used for public purposes. It is reasonable to expect that portions of the site may be used for support of the open-space uses of Waukegan Beach—support includes such functions as supplementary parking or green space.

It is the conclusion of this review that the "reasonably anticipated" future land use at the WCP site does not include residential development. "Reasonably anticipated" future land uses expected and planned for the site are industrial and commercial. The possibility of recreational support uses, such as parking and green space, is consistent with adjacent land uses.

Appendix 3-B

Development of Target Soil Concentrations: Protection of Human Health

Appendix 3-B

Development of Target Soil Concentrations
Protection of Human Health

List of Tables

Appendix 3-B

Development of Target Soil Concentrations
Protection of Human Health

The target soil concentrations (TSC) for protection of human health were derived through use of standard risk equations and default assumptions or a combination of default and site-specific assumptions as presented in the following EPA guidance documents:

- *Risk Assessment Guidance for Superfund: Volume I - Human Health Evaluation Manual Part A, 1989*

- *Risk Assessment Guidance for Superfund: Volume I - Human Health Evaluation Manual Part B, Development of Risk-Based Preliminary Remediation Goals, 1991*

- *Soil Screening Guidance: Technical Background Document, 1996*

- *Exposure Factors Handbook, 1989, 1996*

- *Dermal Exposure Assessment: Principles and Applications, 1992*

TSC Approach

TSCs were developed using models identical to those used in standard EPA risk assessments. However, with the TSC approach, an acceptable level of risk (i.e., 10^{-4}, 10^{-5}, 10^{-6}) was predetermined, and the corresponding acceptable target concentrations of the chemicals of concern were calculated for site-specific exposure scenarios for the site.

The overall approach used in the development of risk-based cleanup goals consisted of the following steps:
1. Selection of target chemicals
2. Definition of future site use
3. Definition of exposure conditions
4. Toxicity assessment
5. Development of target concentrations for the preliminary remediation goals

Target Chemicals

Based on the HHRA completed for this site, the primary contaminants of concern in soil were carcinogenic PAHs and arsenic (U.S. EPA, 1995a). The TSCs also consider the COCs identified for the site in the HHRA—PCBs, benzene, dibenzofuran, 4-methylphenol, and naphthalene.

Future Site Use

Future site use is considered to be industrial and/or commercial. A detailed assessment of future land use considerations is presented in Appendix 3-C.

Exposure Conditions

TSCs are developed based on the extent to which an individual would be likely to come into contact with the target chemicals detected in soils (i.e., the potential for exposure). The exposure assumptions used to develop TSCs for the site were formulated through consideration of the site future land use, potential human receptors, potentially complete exposure pathways, and exposure routes.

Considerable judgement is involved in the development of exposure conditions. In developing the PRGs in the HHRA, two sets of exposure conditions—reasonable maximum exposure (RME) and central tendency exposure (CTE)—were evaluated. In developing the TSCs, a new set of exposure conditions is used—representative high exposure (RHE). The significant distinctions between these exposure conditions are highlighted in the following paragraphs. Each of these exposure scenarios includes a combination of default EPA values for risk assessment as well as site-specific values.

Exposure Pathways

An exposure pathway consists of a contaminated source (i.e., soil), a point of potential contact for humans with the contaminated source, and an exposure route (i.e., ingestion of contaminated soil). The following paragraphs describe these pathways and site-specific conditions.

Soil Pathway—Based on the anticipated future land use, the potential for direct human contact with site soils was assumed to be a viable exposure pathway. It was assumed that the potential human receptors may ingest or come in contact with soils as a result of the following activities:

1. Exposure of construction/utility workers to surface and subsurface (upper 5 feet) soils.

2. Occupational exposure to surface soils at the redeveloped site during normal commercial/industrial land-use activities.

Air Pathway—Contaminants in surface soils could be released to the ambient air through wind-driven erosion or mechanical suspension. The significance of the ambient air inhalation pathway depends on site conditions such as the human behavior patterns, the degree of soil disturbance, the soil chemical concentrations, meteorological conditions, soil moisture, and related soil properties. The air pathway was included in developing the TSCs for the construction/utility and commercial/industrial land use activities.

Exposure Routes

In the development of TSCs, it was assumed that utility, construction, and commercial/industrial workers could be exposed to target chemicals in soil by three exposure routes: incidental soil ingestion, dermal contact with soils, and inhalation of particulates and volatiles released from soils. In developing the PRGs in the HHRA, the U.S. EPA used all three exposure routes for all chemicals of concern except for cPAHs and PCBs. For these compounds, the HHRA did not consider inhalation exposure due to a lack of inhalation toxicity values. In addition, the dermal exposure was assumed to be equivalent to exposure from ingestion in accordance with IEPA guidance. In developing the TSCs, inhalation is treated in the same manner as the PRG calculations. However, dermal contact exposure is considered separately from ingestion because new values for dermal exposure are available in accordance with U.S. EPA guidance (U.S. EPA, 1998). The specifics of the three exposure scenarios are summarized below and in Table 3-B-1.

- Utility Worker

    For the utility worker exposure scenario, it was assumed that a utility worker would be exposed to the upper 5 feet of contaminated soil (the entire depth of the vadose zone) over an exposure domain of approximately 2 acres. This corresponds to one utility construction crew building three utility lines—storm sewer, sanitary sewer, and water lines—along the entire north-south dimension of the site. The exposure frequency was considered to be from 8 to 15 days for the CTE and RME scenarios. For the RHE scenario, this was increased to 60 days based on an estimate of 30 days to perform the work, and an allowance of a factor of 2 for uncertainty in work efficiency. The soil ingestion rate of 216 to 480 mg/day for the CTE and RME exposure scenarios was reduced slightly to 200 mg/day for the RHE scenario based on the mechanized nature of most utility construction work. Finally, for dermal

contact, the CTE and RME exposures used a skin area of from 5,000 to 5,800 cm^2 with an adherence factor ranging from 0.2 to 1.0 mg/cm^2. For the RHE exposure scenario, the value of 5,800 cm^2 of exposed skin was retained as this is representative of the hands, arms and head. However, the low value of 0.2 for adherence of soil to skin was used as this represents an upper bound for irrigation installers.

- Construction Worker

For the construction worker, it was assumed that a construction worker would be exposed to the upper 5 feet of contaminated soil over an exposure domain of approximately 2 to 5 acres. This corresponds to construction of a foundation for a structure the size of OMC's Plant No. 1 south of the site. The exposure frequency used was from 18 to 21 days for the CTE and RME scenarios. For RHE, the exposure frequency was increased to 30 days. Soil ingestion and adherence values for the construction worker scenario were considered equivalent to those used for the construction worker for RME, CTE, and RHE exposure scenarios.

- Commercial or Industrial Workers

To develop a basis for potential occupational exposure under the commercial/industrial scenario, it was assumed that the exposure domain would be on the order of 5 acres. However, most of the site will be covered (soil and vegetation, gravel, asphalt or concrete and buildings), thus limiting exposure. For the RME and CTE scenarios, the exposure frequency was assumed to be 165 days per year with the exposure duration varying from 9 to 25 years. For the RHE scenario, it was assumed that workers may be outdoors for lunch or other activities for 97.5 days/year (the estimated number of decent weather, non-vacation days per year) over a 25-year period. Incidental ingestion was assumed to be from 0.825 to 8.05 grams of contaminated soil per day for CTE and RME, but was reduced to 0.002 for RHE in order to reflect the time spent outdoors in proportion to the total. Similarly, the soil adherence factor ranged from 0.2 to 1.0 for CTE and RME, but was reduced to .043 for RHE. The significantly lower values for RHE were used because it better represents credible exposure values, as explained below. Realistically, after redevelopment it is likely that there will be no opportunity for these workers to contact subsurface soils.

As previously mentioned, the RME and CTE values are typical of conservative preliminary remediation goals, but may be overly conservative for evaluating potential remedial actions during a feasibility study. By comparison, the target soil concentrations calculated using the RHE exposure scenario represent appropriate level of risk for consideration of site-specific future conditions. For most compounds, the exposure conditions which have the greatest sensitivity with regard to future risk are the assumed ingestion rate, exposed skin area, the soil adherence factor, and the exposure frequency. For example, the relatively high ingestion rates considered in the RME and CTE scenarios for the utility/construction worker scenarios exceed the ingestion rate used in the RHE scenario of 200 mg/day. This value is based on an upper value for irrigation installers and is therefore more representative of a reasonable upper bound for ingestion by utility/ construction workers.

Similarly, the ingestion rate, exposed skin area, and exposure frequency for the reasonable high exposure scenario (2 mg/day, 840 cm^2, and 97.5 days/yr) represent upper bound values for future exposure scenarios when considering the limited extent of likely outdoor activities for future industrial/commercial workers and the likely limited exposure to bare soil surfaces. Most new industrial/commercial facilities incorporate significant pavement and landscaping, and most commercial/industrial workers spend the majority of the working day indoors. The soil adherence factor, 0.043 mg/cm^2, is based on soil adherence to the hands of greenhouse workers. Soil adherence factors of 0.2 mg/cm^2 and 1.0 mg/cm^2 correspond respectively to irrigation installers (hands only; arms, legs and face were 0.02 mg/cm^2 or less) and a factor between reed gatherers (hands) and the high-end amount for rugby players.

Toxicity Assessment

The chemical concentration in soil that is considered safe depends, in part, on the inherent chemical toxicity. The toxic effect of a chemical also depends on the dose or concentration of the substance to which an organism is exposed. Toxicity values describe the quantitative dose-response relationship between the chemical dose to which an organism is exposed and the incidence of adverse health effects. The toxicity value for a chemical may differ depending on the route by which an organism is exposed (i.e., by ingestion, inhalation or through dermal contact).

Cancer Risk

The dose-response relationship for carcinogens is expressed as a cancer slope factor or unit risk factor. Generally, the slope factor is a plausible upper-bound estimate of the probability of a response-per-unit intake of a chemical over a lifetime. The slope factor is usually, but not always, the upper 95th percent confidence limit of the slope of the dose-response curve and is expressed as the probability of a response per milligram of chemical per kilogram of body weight per day $(mg/kg\text{-}day)^{-1}$. In risk assessment, the slope factor is used to estimate an upper-bound lifetime probability of an individual developing cancer as a result of exposure to a carcinogen. A unit risk factor is analogous to the slope factor but is expressed in units of $(\mu g/m^3)^{-1}$.

Toxicity values derived by EPA for carcinogenic effects were used to develop the TSCs.

Development of TSCs

The acceptable risk levels for cancer and noncancer effects to determine site cleanup goals is a policy decision, not a risk-based decision. The State of Illinois guidance provides a cancer target risk value of one excess cancer-in-one-hundred-thousand (10^{-5}) over background risk level for the cancer endpoint. This risk criterion was used in the development of the TSCs.

To calculate the acceptable soil concentration for the inhalation pathway, a particulate emission factor (PEF) and volatilization factor (VF) were derived based on guidance provided in EPA's RAGS part B and Soil Screening Guidance document.

To calculate the PRGs, the exposure conditions are combined with the toxicity/cancer risk data for each of the chemicals of concern. The risk values for various soil exposure conditions are summarized in Table 3-B-2.

Using these exposure values and the chemical-specific toxicity/cancer risk values, the target soil concentrations were calculated. The attached spreadsheets, labeled Table 3-B-3 through 3-B-18 present the calculation of the PRGs as well as the target soil concentrations for protection of human health.

References

U.S. EPA, 1989. Exposure Factors Handbook. May, 1989. EPA/600/8-89/043.

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Table 3-B-1

Summary of Exposure Values

	RME	CTE	RHE	Units	Source
All Exposure Scenarios					
Carcinogenic Target Risk	10^{-6}	10^{-6}	10^{-5}		(State of Illinois criteria)
Body Weight	70	70	70	kg	U.S. EPA, 1991
Averaging Time	70	70	70	years	U.S. EPA, 1991
Particulate Emission Factor				Calculated	exposure scenario specific
Volatilization Factor (VF)				Calculated	chemical and exposure scenario specific
Inhalation Rate (IR)	20	20	20	m^3/day	U.S. EPA, 1991
Utility Worker					
Exposure Duration (ED)	1	1	1	year	site specific
Exposure Frequency (EF)	21	8	60	days/year	site specific
Soil Ingestion Rate (IR)	480	216	200	mg/day	U.S. EPA, 1996a
Skin Surface Area (SA)	5,800	5,000	5,800	cm^2	U.S. EPA, 1996a
Soil Adherence Factor (AF)	1	0.2	0.2	mg/cm^2	U.S. EPA, 1996a
Construction Worker					
Exposure Duration (ED)	1	1	1	year	site specific
Exposure Frequency (EF)	21	10	30	days/year	site specific
Soil Ingestion Rate (IR)	480	216	200	mg/day	U.S. EPA, 1996a
Skin Surface Area (SA)	5,800	5,000	5,800	cm^2	U.S. EPA, 1996a
Soil Adherence Factor (AF)	1	0.2	0.2	mg/cm^2	U.S. EPA, 1996a
Commercial/Industrial Worker					
Exposure Duration (ED)	25	9	25	years	U.S. EPA, 1989
Exposure Frequency (EF)	165	165	97.5	days/year	site specific
Soil Ingestion Rate (IR)	50	25	2	mg/day	U.S. EPA, 1996—site specific
Skin Surface Area (SA)	5,800	5,000	840	cm^2	U.S. EPA, 1996a
Soil Adherence Factor (AF)	1.0	0.2	0.043	mg/cm^2	U.S. EPA, 1996a

Table 3B-2
Summary of Soil Risk Values
Waukegan Manufactured Gas and Coke Plant Site
(mg/kg)

Chemical	Residential		Commercial/Industrial			Utility/Construction		
	RME	CTE	RME	CTE	RHE	RME	CTE	RHE
Cancer Risk: 1X10-6								
PCBs	0.12	8.06	0.25	3	31	17	118	16.5
Arsenic	1.09	55.2	2.68	23	205	106	659	94
Benzene	1.91	41.3	3.23	10	6	580	1786	238
Benzo(a)anthracene	1.78	68.1	5.94	33	150	122	709	116
Benzo(a)pyrene	0.18	6.81	0.59	3	15	12	70.9	11.6
Benzo(b)fluranthene	1.78	68.1	5.94	33	150	122	709	116
Dibenzo(a,h)anthracene	0.18	6.81	0.59	3	15	12	70.9	11.6
Indeno(g,h,i)pyrene	1.78	68.1	5.94	33	150	122	709	116
Non-Cancer Risk: HI=1								
Dibenzofuran	653	17033	983	4955	186779	4591	40427	5390
4-Methylphenol	817	21292	1229	6194	233474	5739	50534	6738
Naphthalene	5203	141944	7704	39961	1565513	39438	369220	48556

Table 3B-3

SOIL PRG CONCENTRATIONS - RESIDENTIAL SCENARIO (RME)

PRG DRIVER: CANCER RISK

EXPOSURE MEDIA: SOIL

ROUTE OF EXPOSURE: DERMAL ABSORPTION, INGESTION AND INHALATION

Chemical	Oral Slope Factor [1] (mg/kg-day)-1	Inhalation [1] Slope Factor (mg/kg-day)-1	Dermal Slope Factor [2] (mg/kg-day)-1	VF[4] m3/kg	ABS[3] Factor	PRG mg/kg
PCBs	7.7	1	7.7	NA	0.03	0.12
Arsenic	1.5	15	1.5	NA	0.01	1.09
Benzene	0.029	0.029	0.029	5.00E+03	0.1	1.91
Benzo(a)anthracene	0.73	NA	0.73	3.44E+07	0.13	1.78
Benzo(a)pyrene	7.3	NA	7.3	3.48E+07	0.13	0.18
Benzo(b)fluoranthene	0.73	NA	0.73	1.35E+07	0.13	1.78
Dibenzo(a,h)anthracene	7.3	NA	7.3	4.38E+08	0.13	0.18
Indeno(g,h,i)pyrene	0.73	NA	0.73	3.05E+08	0.13	1.78

Target Risk	1E-06			
EXPOSURE ASSUMPTIONS	Value	Units	Source	
IR-Ingestion Rate	100	mg/day	EPA 7/23/98	
SA-Surface Area (cm2)	5800	cm2	EPA 7/23/98	
AF-Adherence Factor (mg/cm2)	1	mg/cm2	EPA 7/23/98	
BW-Body weight (kg)	70	kg	EPA 7/23/98	
EF-Exposure frequency (days/yr)	230	days/yr	EPA 7/23/98	
ED-Exposure duration (yr)	30	yr	EPA 7/23/98	
ATC-Averaging time (days)	25550	days	EPA 7/23/98	
INHR-Inhalation rate (m3/day)	20	m3/day	EPA 7/23/98	
PEF (m3/kg)	8.600E+09	m3/kg	EPA 7/23/98	
EV (event/day)	1	event/day	EPA 7/23/98	
CF-Conversion factor (kg/mg)	1E-06	kg/mg		

[1] From: "IRIS" or "Region 9: Preliminary Remediation Goals"

[2] Dermal Slope Factor is assumed to equal Oral Slope Factor

[3] From: "EPA 7/23/98" and "Region 9: Preliminary Remediation Goals"

[4] From: Final Technical Memorandum. EPA, 1995

PRG = (TR * ATC* BW) / [(EF * ED) * ((IR * SFo * CF) + (SA * AF * ABS * EV * SFo * CF) + (INHR * SFi * (1/ PEF+1/VF)))]

FOR PAHS: PRG = (TR * ATC* BW) / [(EF * ED) * (IR * SFo * CF) *2]

TABLE 3B-4

PRG CONCENTRATIONS - RESIDENTIAL EXPOSURE SCENARIO (RME)

PRG DRIVER: NONCANCER RISK

EXPOSURE MEDIA: Soil

ROUTE OF EXPOSURE: DERMAL ABSORPTION, INGESTION AND INHALATION

Chemical	Oral RfD[1] mg/kg-day	Inhalation RfD[1] mg/kg-day	Dermal RfD[2] mg/kg-day	VF[4] m3/kg	ABS[3] Factor	PRG mg/kg
Dibenzofuran	0.004	NA	0.004	NA	0.1	653
4-Methylphenol	0.005	NA	0.005	1.09E+06	0.1	817
Naphthalene	0.04	NA	0.04	5.42E+04	0.13	5203
EXPOSURE ASSUMPTIONS	Value	Units	Source			
IR-Ingestion Rate	100	mg/day	EPA 11/14/95			
SA-Surface Area (cm2)	5800	cm2	EPA 11/14/95			
AF-Adherence Factor (mg/cm2)	1	mg/cm2	EPA 11/14/95			
BW-Body weight (kg)	70	kg	EPA 11/14/95			
EF-Exposure frequency (days/yr)	230	days/yr	EPA 11/14/95			
ED-Exposure duration (yr)	30	yr	EPA 11/14/95			
ATNC (days)	10950	days	EPA 11/14/95			
HI-Hazard Index (unitless)	1	unitless	EPA 11/14/95			
INHR-Inhalation Rate (m3/day)	20	m3/day	EPA 11/14/95			
PEF (m3/kg)	8.60E+09	m3/kg	EPA 11/14/95			
EV (event/day)	1	event/day	EPA 11/14/95			
CF-Conversion factor (kg/mg)	1E-06	kg/mg				

[1] From: "IRIS" or "Region 9: Preliminary Remediation Goals"

[2] Dermal Reference Dose is assumed to equal Oral Refernce Dose

[3] From: "Region 9: Preliminary Remediation Goals", 1998

[4] From: Final Technical Memorandum, EPA, 1995

PRG = 1 / (Oral + Inhalation + Dermal)

Oral = (IR * CF * EF * ED) / (RfDo * HI * ATNC * BW)

Inhalation = (INHR * EF * ED * (1/VF + 1/PEF)) / (RfDi * HI * ATNC * BW)

Dermal = (CF * AF * ABS * SA * EV * EF * ED) / (RfDd * HI * ATNC * BW)

Table 3B-5

SOIL PRG CONCENTRATIONS - RESIDENTIAL SCENARIO (CTE)

PRG DRIVER: CANCER RISK

EXPOSURE MEDIA: SOIL

ROUTE OF EXPOSURE: DERMAL ABSORPTION, INGESTION AND INHALATION

Chemical	Oral Slope Factor [1] (mg/kg-day)-1	Inhalation [1] Slope Factor (mg/kg-day)-1	Dermal Slope Factor [2] (mg/kg-day)-1	VF[4] m3/kg	ABS[3] Factor	PRG mg/kg
PCBs	7.7	1	7.7	NA	0.03	8.06
Arsenic	1.5	15	1.5	NA	0.01	55.18
Benzene	0.029	0.029	0.029	5.00E+03	0.1	41.28
Benzo(a)anthracene	0.73	NA	0.73	3.44E+07	0.13	68.06
Benzo(a)pyrene	7.3	NA	7.3	3.48E+07	0.13	6.81
Benzo(b)fluoranthene	0.73	NA	0.73	1.35E+07	0.13	68.06
Dibenzo(a,h)anthracene	7.3	NA	7.3	4.38E+08	0.13	6.81
Indeno(g,h,i)pyrene	0.73	NA	0.73	3.05E+08	0.13	68.06
Target Risk	1E-06					
EXPOSURE ASSUMPTIONS	Value	Units	Source			
IR-Ingestion Rate	50	mg/day	EPA 7/23/98			
SA-Surface Area (cm2)	5000	cm2	EPA 7/23/98			
AF-Adherence Factor (mg/cm2)	0.2	mg/cm2	EPA 7/23/98			
BW-Body weight (kg)	70	kg	EPA 7/23/98			
EF-Exposure frequency (days/yr)	40	days/yr	EPA 7/23/98			
ED-Exposure duration (yr)	9	yr	EPA 7/23/98			
ATC-Averaging time (days)	25550	days	EPA 7/23/98			
INHR-Inhalation rate (m3/day)	20	m3/day	EPA 7/23/98			
PEF (m3/kg)	8.600E+09	m3/kg	EPA 7/23/98			
EV (event/day)	1	event/day	EPA 7/23/98			
CF-Conversion factor (kg/mg)	1E-06	kg/mg				

[1] From: "IRIS" or "Region 9: Preliminary Remediation Goals"

[2] Dermal Slope Factor is assumed to equal Oral Slope Factor

[3] From: "EPA 7/23/98" and "Region 9: Preliminary Remediation Goals"

[4] From: Final Technical Memorandum. EPA, 1995

PRG = (TR * ATC* BW) / [(EF * ED) * ((IR * SFo * CF) + (SA * AF * ABS * EV * SFo * CF) + (INHR * SFi * (1/ PEF+1/VF)))]

FOR PAHS: PRG = (TR * ATC* BW) / [(EF * ED) * (IR * SFo * CF) *2]

TABLE 3B-6

PRG CONCENTRATIONS - RESIDENTIAL EXPOSURE SCENARIO (CTE)

PRG DRIVER: NONCANCER RISK

EXPOSURE MEDIA: Soil

ROUTE OF EXPOSURE: DERMAL ABSORPTION, INGESTION AND INHALATION

Chemical	Oral RfD[1] mg/kg-day	Inhalation RfD[1] mg/kg-day	Dermal RfD[2] mg/kg-day	VF[4] m3/kg	ABS[3] Factor	PRG mg/kg
Dibenzofuran	0.004	NA	0.004	NA	0.1	17033
4-Methylphenol	0.005	NA	0.005	1.09E+06	0.1	21292
Naphthalene	0.04	NA	0.04	5.42E+04	0.13	141944
EXPOSURE ASSUMPTIONS	Value	Units	Source			
IR-Ingestion Rate	50	mg/day	EPA 11/14/95			
SA-Surface Area (cm2)	5000	cm2	EPA 11/14/95			
AF-Adherence Factor (mg/cm2)	0.2	mg/cm2	EPA 11/14/95			
BW-Body weight (kg)	70	kg	EPA 11/14/95			
EF-Exposure frequency (days/yr)	40	days/yr	EPA 11/14/95			
ED-Exposure duration (yr)	9	yr	EPA 11/14/95			
ATNC (days)	3285	days	EPA 11/14/95			
HI-Hazard Index (unitless)	1	unitless	EPA 11/14/95			
INHR-Inhalation Rate (m3/day)	20	m3/day	EPA 11/14/95			
PEF (m3/kg)	8.60E+09	m3/kg	EPA 11/14/95			
EV (event/day)	1	event/day	EPA 11/14/95			
CF-Conversion factor (kg/mg)	1E-06	kg/mg				

[1] From: "IRIS" or "Region 9: Preliminary Remediation Goals"

[2] Dermal Reference Dose is assumed to equal Oral Refernce Dose

[3] From: "Region 9: Preliminary Remediation Goals", 1998

[4] From: Final Technical Memorandum. EPA, 1995

PRG = 1 / (Oral + Inhalation + Dermal)

   Oral = (IR * CF * EF * ED) / (RfDo * HI * ATNC * BW)

   Inhalation = (INHR * EF * ED * (1/VF + 1/PEF)) / (RfDi * HI * ATNC * BW)

   Dermal = (CF * AF * ABS * SA * EV * EF * ED) / (RfDd * HI * ATNC * BW)

Table 3B-7

SOIL PRG CONCENTRATIONS - COMMERCIAL/INDUSTRIAL SCENARIO (RME)

PRG DRIVER: CANCER RISK

EXPOSURE MEDIA: SOIL

ROUTE OF EXPOSURE: DERMAL ABSORPTION, INGESTION AND INHALATION

Chemical	Oral Slope Factor [1] (mg/kg-day)-1	Inhalation [1] Slope Factor (mg/kg-day)-1	Dermal Slope Factor [2] (mg/kg-day)-1	VF[4] m3/kg	ABS[3] Factor	PRG mg/kg
PCBs	7.7	1	7.7	NA	0.03	0.25
Arsenic	1.5	15	1.5	NA	0.01	2.68
Benzene	0.029	0.029	0.029	5.00E+03	0.1	3.23
Benzo(a)anthracene	0.73	NA	0.73	3.44E+07	0.13	5.94
Benzo(a)pyrene	7.3	NA	7.3	3.48E+07	0.13	0.59
Benzo(b)fluoranthene	0.73	NA	0.73	1.35E+07	0.13	5.94
Dibenzo(a,h)anthracene	7.3	NA	7.3	4.38E+08	0.13	0.59
Indeno(g,h,i)pyrene	0.73	NA	0.73	3.05E+08	0.13	5.94
Target Risk	1E-06					

EXPOSURE ASSUMPTIONS	Value	Units	Source
IR-Ingestion Rate	50	mg/day	EPA 7/23/98
SA-Surface Area (cm2)	5800	cm2	EPA 7/23/98
AF-Adherence Factor (mg/cm2)	1	mg/cm2	EPA 7/23/98
BW-Body weight (kg)	70	kg	EPA 7/23/98
EF-Exposure frequency (days/yr)	165	days/yr	EPA 7/23/98
ED-Exposure duration (yr)	25	yr	EPA 7/23/98
ATC-Averaging time (days)	25550	days	EPA 7/23/98
INHR-Inhalation rate (m3/day)	20	m3/day	EPA 7/23/98
PEF (m3/kg)	8.600E+09	m3/kg	EPA 7/23/98
EV (event/day)	1	event/day	EPA 7/23/98
CF-Conversion factor (kg/mg)	1E-06	kg/mg	

[1] From: "IRIS" or "Region 9: Preliminary Remediation Goals"

[2] Dermal Slope Factor is assumed to equal Oral Slope Factor

[3] From: "EPA 7/23/98" and "Region 9: Preliminary Remediation Goals"

[4] From: Final Technical Memorandum. EPA, 1995

PRG = (TR * ATC* BW) / [(EF * ED) * ((IR * SFo * CF) + (SA * AF * ABS * EV * SFo * CF) + (INHR * SFi * (1/ PEF+1/VF)))]

FOR PAHS: PRG = (TR * ATC* BW) / [(EF * ED) * (IR * SFo * CF) *2]

TABLE 3B-8

PRG CONCENTRATIONS - COMMERCIAL/INDUSTRIAL SCENARIO (RME)

PRG DRIVER: NONCANCER RISK

EXPOSURE MEDIA: Soil

ROUTE OF EXPOSURE: DERMAL ABSORPTION, INGESTION AND INHALATION

Chemical	Oral RfD[1] mg/kg-day	Inhalation RfD[1] mg/kg-day	Dermal RfD[2] mg/kg-day	VF[4] m3/kg	ABS[3] Factor	PRG mg/kg
Dibenzofuran	0.004	NA	0.004	NA	0.1	983
4-Methylphenol	0.005	NA	0.005	1.09E+06	0.1	1229
Naphthalene	0.04	NA	0.04	5.42E+04	0.13	7704
EXPOSURE ASSUMPTIONS	**Value**	**Units**	**Source**			
IR-Ingestion Rate	50	mg/day	EPA 7/23/98			
SA-Surface Area (cm2)	5800	cm2	EPA 7/23/98			
AF-Adherence Factor (mg/cm2)	1	mg/cm2	EPA 7/23/98			
BW-Body weight (kg)	70	kg	EPA 7/23/98			
EF-Exposure frequency (days/yr)	165	days/yr	EPA 7/23/98			
ED-Exposure duration (yr)	25	yr	EPA 7/23/98			
ATNC (days)	9125	days	EPA 7/23/98			
HI-Hazard Index (unitless)	1	unitless	EPA 7/23/98			
INHR-Inhalation Rate (m3/day)	20	m3/day	EPA 7/23/98			
PEF (m3/kg)	8.60E+09	m3/kg	EPA 7/23/98			
EV (event/day)	1	event/day	EPA 7/23/98			
CF-Conversion factor (kg/mg)	1E-06	kg/mg				

[1] From: "IRIS" or "Region 9: Preliminary Remediation Goals"

[2] Dermal Reference Dose is assumed to equal Oral Refernce Dose

[3] From: "Region 9: Preliminary Remediation Goals", 1998

[4] From: Final Technical Memorandum. EPA, 1995

PRG = 1 / (Oral + Inhalation + Dermal)

Oral = (IR * CF * EF * ED) / (RfDo * HI * ATNC * BW)

Inhalation = (INHR * EF * ED * (1/VF + 1/PEF)) / (RfDi * HI * ATNC * BW)

Dermal = (CF * AF * ABS * SA * EV * EF * ED) / (RfDd * HI * ATNC * BW)

Table 3B-9
SOIL PRG CONCENTRATIONS - COMMERCIAL/INDUSTIAL SCENARIO (CTE)
PRG DRIVER: CANCER RISK
EXPOSURE MEDIA: SOIL
ROUTE OF EXPOSURE: DERMAL ABSORPTION, INGESTION AND INHALATION

Chemical	Oral Slope Factor [1] (mg/kg-day)-1	Inhalation [1] Slope Factor (mg/kg-day)-1	Dermal Slope Factor [2] (mg/kg-day)-1	VF[4] m3/kg	ABS[3] Factor	PRG mg/kg
PCBs	7.7	NA	7.7	NA	0.03	2.84
Arsenic	1.5	15	1.5	NA	0.01	22.93
Benzene	0.029	0.029	0.029	5.00E+03	0.1	10.07
Benzo(a)anthracene	0.73	NA	0.73	3.44E+07	0.13	33.00
Benzo(a)pyrene	7.3	NA	7.3	3.48E+07	0.13	3.30
Benzo(b)fluoranthene	0.73	NA	0.73	1.35E+07	0.13	33.00
Dibenzo(a,h)anthracene	7.3	NA	7.3	4.38E+08	0.13	3.30
Indeno(g,h,i)pyrene	0.73	NA	0.73	3.05E+08	0.13	33.00
Target Risk	1E-06					
EXPOSURE ASSUMPTIONS	Value	Units	Source			
IR-Ingestion Rate	25	mg/day	EPA 11/14/95			
SA-Surface Area (cm2)	5000	cm2	EPA 11/14/95			
AF-Adherence Factor (mg/cm2)	0.2	mg/cm2	EPA 11/14/95			
BW-Body weight (kg)	70	kg	EPA 11/14/95			
EF-Exposure frequency (days/yr)	165	days/yr	EPA 11/14/95			
ED-Exposure duration (yr)	9	yr	EPA 11/14/95			
ATC-Averaging time (days)	25550	days	EPA 11/14/95			
INHR-Inhalation rate (m3/day)	20	m3/day	EPA 11/14/95			
PEF (m3/kg)	8.600E+09	m3/kg	EPA 11/14/95			
EV (event/day)	1	event/day	EPA 11/14/95			
CF-Conversion factor (kg/mg)	1E-06	kg/mg				

[1] From: "IRIS" or "Region 9: Preliminary Remediation Goals"

[2] Dermal Slope Factor is assumed to equal Oral Slope Factor

[3] From: "EPA 7/23/98" and "Region 9: Preliminary Remediation Goals"

[3] From: "EPA 7/23/98" and "Region 9: Preliminary Remediation Goals"

PRG = (TR * ATC* BW) / [(EF * ED) * ((IR * SFo * CF) + (SA * AF * ABS * EV * SFo * CF) + (INHR * SFi * (1/ PEF+1/VF)))]

FOR PAHS: PRG = (TR * ATC* BW) / [(EF * ED) * (IR * SFo * CF) *2]

TABLE 3B-10
PRG CONCENTRATIONS - COMMERCIAL/INDUSTRIAL EXPOSURE SCENARIO (CTE)
PRG DRIVER: NONCANCER RISK
EXPOSURE MEDIA: Soil
ROUTE OF EXPOSURE: DERMAL ABSORPTION, INGESTION AND INHALATION

Chemical	Oral RfD[1] mg/kg-day	Inhalation RfD[1] mg/kg-day	Dermal RfD[2] mg/kg-day	VF[4] m3/kg	ABS[3] Factor	PRG mg/kg
Dibenzofuran	0.004	NA	0.004	NA	0.1	4955
4-Methylphenol	0.005	NA	0.005	1.09E+06	0.1	6194
Naphthalene	0.04	NA	0.04	5.42E+04	0.13	39961
EXPOSURE ASSUMPTIONS	Value	Units	Source			
IR-Ingestion Rate	25	mg/day	EPA 11/14/95			
SA-Surface Area (cm2)	5000	cm2	EPA 11/14/95			
AF-Adherence Factor (mg/cm2)	0.2	mg/cm2	EPA 11/14/95			
BW-Body weight (kg)	70	kg	EPA 11/14/95			
EF-Exposure frequency (days/yr)	165	days/yr	EPA 11/14/95			
ED-Exposure duration (yr)	9	yr	EPA 11/14/95			
ATNC (days)	3285	days	EPA 11/14/95			
HI-Hazard Index (unitless)	1	unitless	EPA 11/14/95			
INHR-Inhalation Rate (m3/day)	20	m3/day	EPA 11/14/95			
PEF (m3/kg)	8.60E+09	m3/kg	EPA 11/14/95			
EV (event/day)	1	event/day	EPA 11/14/95			
CF-Conversion factor (kg/mg)	1E-06	kg/mg				

[1] From: "IRIS" or "Region 9: Preliminary Remediation Goals"

[2] Dermal Reference Dose is assumed to equal Oral Refernce Dose

[3] From: "Region 9: Preliminary Remediation Goals". 1998

[4] From: Final Technical Memorandum. EPA, 1995

PRG = 1 / (Oral + Inhalation + Dermal)

Oral = (IR * CF * EF * ED) / (RfDo * HI * ATNC * BW)

Inhalation = (INHR * EF * ED * (1/VF + 1/PEF)) / (RfDi * HI * ATNC * BW)

Dermal = (CF * AF * ABS * SA * EV * EF * ED) / (RfDd * HI * ATNC * BW)

Table 3B-11

SOIL TSC CONCENTRATIONS - COMMERCIAL/INDUSTRIAL SCENARIO (RHE)

TSC DRIVER: CANCER RISK

EXPOSURE MEDIA: SOIL

ROUTE OF EXPOSURE: DERMAL ABSORPTION, INGESTION AND INHALATION

Chemical	Oral Slope Factor [1] (mg/kg-day)-1	Inhalation [1] Slope Factor (mg/kg-day)-1	Dermal Slope Factor [2] (mg/kg-day)-1	VF[4] m3/kg	ABS[3] Factor	TSC mg/kg
PCBs	7.7	NA	7.7	NA	0.03	30.90
Arsenic	1.5	15	1.5	NA	0.01	205.15
Benzene	0.029	0.029	0.029	5.00E+03	0.1	6.32
Benzo(a)anthracene	0.73	NA	0.73	3.44E+07	0.13	150.12
Benzo(a)pyrene	7.3	NA	7.3	3.48E+07	0.13	15.01
Benzo(b)fluoranthene	0.73	NA	0.73	1.35E+07	0.13	150.12
Dibenzo(a,h)anthracene	7.3	NA	7.3	4.38E+08	0.13	15.01
Indeno(g,h,i)pyrene	0.73	NA	0.73	3.05E+08	0.13	150.12

Target Risk	1E-06		
EXPOSURE ASSUMPTIONS	Value	Units	Source
IR-Ingestion Rate	2	mg/day	Site specific
SA-Surface Area (cm2)	840	cm2	EPA 1996
AF-Adherence Factor (mg/cm2)	0.043	mg/cm2	EPA 1996
BW-Body weight (kg)	70	kg	EPA 1996
EF-Exposure frequency (days/yr)	97.5	days/yr	Site sspecific
ED-Exposure duration (yr)	25	yr	EPA 1996
ATC-Averaging time (days)	25550	days	EPA 1996
INHR-Inhalation rate (m3/day)	20	m3/day	EPA 1996
PEF (m3/kg)	8.600E+09	m3/kg	EPA 11/14/95
EV (event/day)	1	event/day	EPA 11/14/95
CF-Conversion factor (kg/mg)	1E-06	kg/mg	

[1] From: "IRIS" or "Region 9: Preliminary Remediation Goals"

[2] Dermal Slope Factor is assumed to equal Oral Slope Factor

[3] From: "EPA 7/23/98" and "Region 9: Preliminary Remediation Goals"

[3] From: "EPA 7/23/98" and "Region 9: Preliminary Remediation Goals"

PRG = (TR * ATC* BW) / [(EF * ED) * ((IR * SFo * CF) + (SA * AF * ABS * EV * SFo * CF) + (INHR * SFi * (1/ PEF+1/VF)))]

TABLE 3B-12

TSC CONCENTRATIONS - COMMERCIAL/INDUSTRIAL EXPOSURE SCENARIO (RHE)

TSC DRIVER: NONCANCER RISK

EXPOSURE MEDIA: Soil

ROUTE OF EXPOSURE: DERMAL ABSORPTION, INGESTION AND INHALATION

Chemical	Oral RfD[1] mg/kg-day	Inhalation RfD[1] mg/kg-day	Dermal RfD[2] mg/kg-day	VF[4] m3/kg	ABS[3] Factor	TSC mg/kg
Dibenzofuran	0.004	NA	0.004	NA	0.1	186779
4-Methylphenol	0.005	NA	0.005	1.09E+06	0.1	233474
Naphthalene	0.04	NA	0.04	5.42E+04	0.13	1565513
EXPOSURE ASSUMPTIONS	Value	Units	Source			
IR-Ingestion Rate	2	mg/day	Site specific			
SA-Surface Area (cm2)	840	cm2	Site specific			
AF-Adherence Factor (mg/cm2)	0.043	mg/cm2	EPA 1996			
BW-Body weight (kg)	70	kg	EPA 1996			
EF-Exposure frequency (days/yr)	97.5	days/yr	Site specific			
ED-Exposure duration (yr)	25	yr	EPA 1996			
ATNC (days)	9125	days	EPA 1996			
HI-Hazard Index (unitless)	1	unitless	EPA 1989			
INHR-Inhalation Rate (m3/day)	20	m3/day	EPA 1996			
PEF (m3/kg)	8.60E+09	m3/kg	EPA 7/23/98			
EV (event/day)	1	event/day	Site specific			
CF-Conversion factor (kg/mg)	1E-06	kg/mg				

[1] From: "IRIS" or "Region 9: Preliminary Remediation Goals"

[2] Dermal Reference Dose is assumed to equal Oral Refernce Dose

[3] From: "Region 9: Preliminary Remediation Goals". 1998

[4] From: Final Technical Memorandum. EPA. 1995

PRG = 1 / (Oral + Inhalation + Dermal)

   Oral = (IR * CF * EF * ED) / (RfDo * HI * ATNC * BW)

   Inhalation = (INHR * EF * ED * (1/VF + 1/PEF)) / (RfDi * HI * ATNC * BW)

   Dermal = (CF * AF * ABS * SA * EV * EF * ED) / (RfDd * HI * ATNC * BW)

Table 3B-13

SOIL PRG CONCENTRATIONS - UTILITY WORKER SCENARIO (RME)

PRG DRIVER: CANCER RISK

EXPOSURE MEDIA: SOIL

ROUTE OF EXPOSURE: DERMAL ABSORPTION, INGESTION AND INHALATION

Chemical	Oral Slope Factor [1] (mg/kg-day)-1	Inhalation [1] Slope Factor (mg/kg-day)-1	Dermal Slope Factor [2] (mg/kg-day)-1	VF[4] m3/kg	ABS[3] Factor	PRG mg/kg
PCBs	7.7	NA	7.7	NA	0.03	16.91
Arsenic	1.5	15	1.5	NA	0.01	105.53
Benzene	0.029	0.029	0.029	5.00E+03	0.1	580.39
Benzo(a)anthracene	0.73	NA	0.73	3.44E+07	0.13	121.53
Benzo(a)pyrene	7.3	NA	7.3	3.48E+07	0.13	12.15
Benzo(b)fluoranthene	0.73	NA	0.73	1.35E+07	0.13	121.53
Dibenzo(a,h)anthracene	7.3	NA	7.3	4.38E+08	0.13	12.15
Indeno(g,h,i)pyrene	0.73	NA	0.73	3.05E+08	0.13	121.53
Target Risk	1E-06					
EXPOSURE ASSUMPTIONS	Value	Units	Source			
IR-Ingestion Rate	480	mg/day	EPA 7/23/98			
SA-Surface Area (cm2)	5800	cm2	EPA 7/23/38			
AF-Adherence Factor (mg/cm2)	1	mg/cm2	EPA 7/23/98			
BW-Body weight (kg)	70	kg	EPA 7/23/98			
EF-Exposure frequency (days/yr)	21	days/yr	EPA 7/23/98			
ED-Exposure duration (yr)	1	yr	EPA 7/23/98			
ATC-Averaging time (days)	25550	days	EPA 7/23/98			
INHR-Inhalation rate (m3/day)	20	m3/day	EPA 7/23/98			
PEF (m3/kg)	4.300E+09	m3/kg	EPA 7/23/98			
EV (event/day)	1	event/day	EPA 7/23/98			
CF-Conversion factor (kg/mg)	1E-06	kg/mg				

[1] From: "IRIS" or "Region 9: Preliminary Remediation Goals"

[2] Dermal Slope Factor is assumed to equal Oral Slope Factor

[3] From: "EPA 7/23/98" and "Region 9: Preliminary Remediation Goals"

[3] From: "EPA 7/23/98" and "Region 9: Preliminary Remediation Goals"

PRG = (TR * ATC* BW) / [(EF * ED) * ((IR * SFo * CF) + (SA * AF * ABS * EV * SFo * CF) + (INHR * SFi * (1/ PEF+1/VF)))]

FOR PAHS: PRG = (TR * ATC* BW) / [(EF * ED) * (IR * SFo * CF) *2]

TABLE 3B-14

PRG CONCENTRATIONS - UTILITY WORKER (RME)

PRG DRIVER: NONCANCER RISK

EXPOSURE MEDIA: Soil

ROUTE OF EXPOSURE: DERMAL ABSORPTION, INGESTION AND INHALATION

Chemical	Oral RfD[1] mg/kg-day	Inhalation RfD[1] mg/kg-day	Dermal RfD[2] mg/kg-day	VF[4] m3/kg	ABS[3] Factor	PRG mg/kg
Dibenzofuran	0.004	NA	0.004	NA	0.1	4591
4-Methylphenol	0.005	NA	0.005	1.09E+06	0.1	5739
Naphthalene	0.04	NA	0.04	5.42E+04	0.13	39438
EXPOSURE ASSUMPTIONS	**Value**	**Units**	**Source**			
IR-Ingestion Rate	480	mg/day	EPA 7/23/98			
SA-Surface Area (cm2)	5800	cm2	EPA 7/23/98			
AF-Adherence Factor (mg/cm2)	1	mg/cm2	EPA 7/23/98			
BW-Body weight (kg)	70	kg	EPA 7/23/98			
EF-Exposure frequency (days/yr)	21	days/yr	EPA 7/23/98			
ED-Exposure duration (yr)	1	yr	EPA 7/23/98			
ATNC (days)	365	days	EPA 7/23/98			
HI-Hazard Index (unitless)	1	unitless	EPA 7/23/98			
INHR-Inhalation Rate (m3/day)	20	m3/day	EPA 7/23/98			
PEF (m3/kg)	4.30E+09	m3/kg	EPA 7/23/98			
EV (event/day)	1	event/day	EPA 7/23/98			
CF-Conversion factor (kg/mg)	1E-06	kg/mg				

[1] From: "IRIS" or "Region 9: Preliminary Remediation Goals"

[2] Dermal Reference Dose is assumed to equal Oral Refernce Dose

[3] From: "Region 9: Preliminary Remediation Goals", 1998

[4] From: Final Technical Memorandum. EPA, 1995

PRG = 1 / (Oral + Inhalation + Dermal)

Oral = (IR * CF * EF * ED) / (RfDo * HI * ATNC * BW)

Inhalation = (INHR * EF * ED * (1/VF + 1/PEF)) / (RfDi * HI * ATNC * BW)

Dermal = (CF * AF * ABS * SA * EV * EF * ED) / (RfDd * HI * ATNC * BW)

Table 3B-15

SOIL PRG CONCENTRATIONS - UTILITY WORKER SCENARIO (CTE)

PRG DRIVER: CANCER RISK

EXPOSURE MEDIA: SOIL

ROUTE OF EXPOSURE: DERMAL ABSORPTION, INGESTION AND INHALATION

Chemical	Oral Slope Factor [1] (mg/kg-day)-1	Inhalation [1] Slope Factor (mg/kg-day)-1	Dermal Slope Factor [2] (mg/kg-day)-1	VF[4] m3/kg	ABS[3] Factor	PRG mg/kg
PCBs	7.7	NA	7.7	NA	0.03	118.02
Arsenic	1.5	15	1.5	NA	0.01	659.34
Benzene	0.029	0.029	0.029	5.00E+03	0.1	1786.15
Benzo(a)anthracene	0.73	NA	0.73	3.44E+07	0.13	708.91
Benzo(a)pyrene	7.3	NA	7.3	3.48E+07	0.13	70.89
Benzo(b)fluoranthene	0.73	NA	0.73	1.35E+07	0.13	708.91
Dibenzo(a,h)anthracene	7.3	NA	7.3	4.38E+08	0.13	70.89
Indeno(g,h,i)pyrene	0.73	NA	0.73	3.05E+08	0.13	708.91
Target Risk	1E-06					

EXPOSURE ASSUMPTIONS	Value	Units	Source
IR-Ingestion Rate	216	mg/day	EPA 11/14/95
SA-Surface Area (cm2)	5000	cm2	EPA 11/14/95
AF-Adherence Factor (mg/cm2)	0.2	mg/cm2	EPA 11/14/95
BW-Body weight (kg)	70	kg	EPA 11/14/95
EF-Exposure frequency (days/yr)	8	days/yr	EPA 11/14/95
ED-Exposure duration (yr)	1	yr	EPA 11/14/95
ATC-Averaging time (days)	25550	days	EPA 11/14/95
INHR-Inhalation rate (m3/day)	20	m3/day	EPA 11/14/95
PEF (m3/kg)	4.300E+09	m3/kg	EPA 11/14/95
EV (event/day)	1	event/day	EPA 11/14/95
CF-Conversion factor (kg/mg)	1E-06	kg/mg	

[1] From: "IRIS" or "Region 9: Preliminary Remediation Goals"

[2] Dermal Slope Factor is assumed to equal Oral Slope Factor

[3] From: "EPA 7/23/98" and "Region 9: Preliminary Remediation Goals"

[3] From: "EPA 7/23/98" and "Region 9: Preliminary Remediation Goals"

PRG = (TR * ATC * BW) / [(EF * ED) * ((IR * SFo * CF) + (SA * AF * ABS * EV * SFo * CF) + (INHR * SFi * (1/ PEF+1/VF)))]

FOR PAHS: PRG = (TR * ATC * BW) / [(EF * ED) * (IR * SFo * CF) *2]

TABLE 3B-16
PRG CONCENTRATIONS - UTILITY WORKER (CTE)
PRG DRIVER: NONCANCER RISK
EXPOSURE MEDIA: Soil
ROUTE OF EXPOSURE: DERMAL ABSORPTION, INGESTION AND INHALATION

Chemical	Oral RfD[1] mg/kg-day	Inhalation RfD[1] mg/kg-day	Dermal RfD[2] mg/kg-day	VF[4] m3/kg	ABS[3] Factor	PRG mg/kg
Dibenzofuran	0.004	NA	0.004	NA	0.1	40427
4-Methylphenol	0.005	NA	0.005	1.09E+06	0.1	50534
Naphthalene	0.04	NA	0.04	5.42E+04	0.13	369220
EXPOSURE ASSUMPTIONS	Value	Units	Source			
IR-Ingestion Rate	216	mg/day	EPA 11/14/95			
SA-Surface Area (cm2)	5000	cm2	EPA 11/14/95			
AF-Adherence Factor (mg/cm2)	0.2	mg/cm2	EPA 11/14/95			
BW-Body weight (kg)	70	kg	EPA 11/14/95			
EF-Exposure frequency (days/yr)	8	days/yr	EPA 11/14/95			
ED-Exposure duration (yr)	1	yr	EPA 11/14/95			
ATNC (days)	365	days	EPA 11/14/95			
HI-Hazard Index (unitless)	1	unitless	EPA 11/14/95			
INHR-Inhalation Rate (m3/day)	20	m3/day	EPA 11/14/95			
PEF (m3/kg)	4.30E+09	m3/kg	EPA 11/14/95			
EV (event/day)	1	event/day	EPA 11/14/95			
CF-Conversion factor (kg/mg)	1E-06	kg/mg				

[1] From: "IRIS" or "Region 9: Preliminary Remediation Goals"

[2] Dermal Reference Dose is assumed to equal Oral Refernce Dose

[3] From: "Region 9: Preliminary Remediation Goals", 1998

[4] From: Final Technical Memorandum. EPA, 1995

PRG = 1 / (Oral + Inhalation + Dermal)

Oral = (IR * CF * EF * ED) / (RfDo * HI * ATNC * BW)

Inhalation = (INHR * EF * ED * (1/VF + 1/PEF)) / (RfDi * HI * ATNC * BW)

Dermal = (CF * AF * ABS * SA * EV * EF * ED) / (RfDd * HI * ATNC * BW)

Table 3B-17

SOIL TSC CONCENTRATIONS - UTILITY WORKER SCENARIO (RHE)

TSC DRIVER: CANCER RISK

EXPOSURE MEDIA: SOIL

ROUTE OF EXPOSURE: DERMAL ABSORPTION, INGESTION AND INHALATION

Chemical	Oral Slope Factor [1] (mg/kg-day)-1	Inhalation [1] Slope Factor (mg/kg-day)-1	Dermal Slope Factor [2] (mg/kg-day)-1	VF[4] m3/kg	ABS[3] Factor	TSC mg/kg
PCBs	7.7	1	7.7	NA	0.03	16.49
Arsenic	1.5	15	1.5	NA	0.01	93.89
Benzene	0.029	0.029	0.029	5.00E+03	0.1	238.15
Benzo(a)anthracene	0.73	NA	0.73	3.44E+07	0.13	116.40
Benzo(a)pyrene	7.3	NA	7.3	3.48E+07	0.13	11.64
Benzo(b)fluoranthene	0.73	NA	0.73	1.35E+07	0.13	116.40
Dibenzo(a,h)anthracene	7.3	NA	7.3	4.38E+08	0.13	11.64
Indeno(g,h,i)pyrene	0.73	NA	0.73	3.05E+08	0.13	116.40

Target Risk	1E-06		
EXPOSURE ASSUMPTIONS	Value	Units	Source
IR-Ingestion Rate	200	mg/day	EPA 11/14/95
SA-Surface Area (cm2)	5800	cm2	EPA 11/14/95
AF-Adherence Factor (mg/cm2)	0.2	mg/cm2	EPA 11/14/95
BW-Body weight (kg)	70	kg	EPA 11/14/95
EF-Exposure frequency (days/yr)	60	days/yr	Site specific
ED-Exposure duration (yr)	1	yr	Site specific
ATC-Averaging time (days)	25550	days	EPA 11/14/95
INHR-Inhalation rate (m3/day)	20	m3/day	EPA 11/14/95
PEF (m3/kg)	4.300E+09	m3/kg	EPA 11/14/95
EV (event/day)	1	event/day	EPA 11/14/95
CF-Conversion factor (kg/mg)	1E-06	kg/mg	

[1] From: "IRIS" or "Region 9: Preliminary Remediation Goals"

[2] Dermal Slope Factor is assumed to equal Oral Slope Factor

[3] From: "EPA 7/23/98" and "Region 9: Preliminary Remediation Goals"

[3] From: "EPA 7/23/98" and "Region 9: Preliminary Remediation Goals"

PRG = (TR * ATC * BW) / [(EF * ED) * ((IR * SFo * CF) + (SA * AF * ABS * EV * SFo * CF) + (INHR * SFi * (1/ PEF+1/VF)))]

TABLE 3B-18

TSC CONCENTRATIONS - UTILITY WORKER (RHE)

TSC DRIVER: NONCANCER RISK

EXPOSURE MEDIA: Soil

ROUTE OF EXPOSURE: DERMAL ABSORPTION, INGESTION AND INHALATION

Chemical	Oral RfD[1] mg/kg-day	Inhalation RfD[1] mg/kg-day	Dermal RfD[2] mg/kg-day	VF[4] m3/kg	ABS[3] Factor	TSC mg/kg
Dibenzofuran	0.004	NA	0.004	NA	0.1	5390
4-Methylphenol	0.005	NA	0.005	1.09E+06	0.1	6738
Naphthalene	0.04	NA	0.04	5.42E+04	0.13	48556
EXPOSURE ASSUMPTIONS	Value	Units	Source			
IR-Ingestion Rate	200	mg/day	EPA 11/14/95			
SA-Surface Area (cm2)	5800	cm2	EPA 11/14/95			
AF-Adherence Factor (mg/cm2)	0.2	mg/cm2	EPA 11/14/95			
BW-Body weight (kg)	70	kg	EPA 11/14/95			
EF-Exposure frequency (days/yr)	60	days/yr	Site specific			
ED-Exposure duration (yr)	1	yr	Site specific			
ATNC (days)	365	days	Site specific			
HI-Hazard Index (unitless)	1	unitless	EPA 1989			
INHR-Inhalation Rate (m3/day)	20	m3/day	EPA 11/14/95			
PEF (m3/kg)	4.30E+09	m3/kg	EPA 11/14/95			
EV (event/day)	1	event/day	EPA 11/14/95			
CF-Conversion factor (kg/mg)	1E-06	kg/mg				

[1] From: "IRIS" or "Region 9: Preliminary Remediation Goals"

[2] Dermal Reference Dose is assumed to equal Oral Refernce Dose

[3] From: "Region 9: Preliminary Remediation Goals". 1998

[4] From: Final Technical Memorandum. EPA, 1995

PRG = 1 / (Oral + Inhalation + Dermal)

   Oral = (IR * CF * EF * ED) / (RfDo * HI * ATNC * BW)

   Inhalation = (INHR * EF * ED * (1/VF + 1/PEF)) / (RfDi * HI * ATNC * BW)

   Dermal = (CF * AF * ABS * SA * EV * EF * ED) / (RfDd * HI * ATNC * BW)

Appendix 3-C

Development of Target Soil Concentrations: Protection of Groundwater

Appendix 3-C

Development of Target Soil
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Appendix 3-C

Development of Target Soil
Concentrations for Protection of Groundwater

This appendix presents the process used to calculate the TSCs for protection of groundwater. A site-specific calculation was used to determine a concentration of arsenic in soil that may result in concentrations of chemicals in the groundwater in excess of promulgated groundwater quality criteria. Illinois EPA guidance was used to calculate site-specific values for other COCs. A TSC for arsenic was calculated separately because arsenic is one of the more mobile contaminants of the COCs. In addition, the distribution of arsenic in the soil at the site is more diffuse than other COCs. As a result, the area which would likely need to be managed to control the potential migration of arsenic would be larger than the area required for management of other COCs.

Impacts to the deep portion of the sand aquifer have been characterized in the conceptual model for the site (Section 2). The concentrations of materials in the deep portion of the sand aquifer are not associated with the current concentrations of materials in the soil. For this reason, development of a TSC to protect groundwater was based on the shallow portion of the sand aquifer only.

To develop this TSC, all available arsenic data from the shallow portion of the sand aquifer was used. For each shallow monitoring well, a simple average concentration of arsenic was calculated using all available data as shown in Table 3-C-1. Next, all analytical results for arsenic in soil from the ground surface to 20 feet below the ground surface was reviewed and assigned to one or more groundwater wells at the site based on location and the direction of groundwater flow. For each monitoring well, the average of these soil samples was computed. The results of this work are presented in Table 3-C-2. Using these average values, a correlation was developed. The plot of this correlation is shown in Figure 3-C-1. To calculate the correlation, four sets of values were not used. The data from monitoring wells MW-3S, MW-5S and MW-6S showed relatively high concentrations of arsenic in groundwater which did not correlate to the low concentrations of arsenic in the surrounding soils. This is likely due to higher concentrations of arsenic in upgradient soil influencing the concentration observed in the wells as much or more than the concentrations in soil in the immediate vicinity of the wells. The results from monitoring well MW-9S also do not appear to fall within a linear range for the relationship between soil and groundwater. While arsenic concentrations in the soil around MW-9S were high, the concentrations in the groundwater were also high. This result appears to be consistent with the concept that the correlation between

concentrations in the soil and the concentrations in the groundwater is linear over a small range and that the concentrations in the soil reach an upper limit at which point the concentration in groundwater will increase independent of the concentration in the soil. At this point, the soil has reached its sorptive capacity.

The remaining seven values are plotted on Figure 3-C-1. The results of the linear regression for this line are included in Table 3-C-3. Using the equation for this line, the soil concentration which corresponds to 0.05 mg/l in the groundwater (the Illinois Class I standard for arsenic) is calculated to be 25 mg/kg. This value is the site-specific TSC for protecting groundwater.

As previously stated because of the distributed nature of arsenic in site soil, it is likely that arsenic will delineate the extent of soil that may need to be managed to protect groundwater. However, other potential contaminants of concern may be present in soil that may need to be managed to protect groundwater. Table 3-C-4 lists the soil concentrations for other COCs that would be protective of groundwater. The list of other COCs includes all parameters which were identified in the shallow groundwater above the MCLs. The values include the U.S.EPA's generic soil screening levels as well as the generic Illinois TACO values for protection of groundwater to Class II standards, and calculated site-specific values based on Illinois guidance.

Table 3C-1
Average Total Arsenic Concentrations in Shallow Groundwater
Waukegan Manufactured Gas & Coke Plant Site

Well	Total Arsenic (ug/L)				Average Total Arsenic
	4/92 or 10/93	12/93	7/96	9/97	
MW1S	120.0	152.0	153.0		141.67
MW3S	134.0	1,700.0	400.0		744.67
MW4S	18.4	25.9	30.9		25.07
MW5S	243.0	251.0	352.0		282.00
MW6S	350.0	343.0	135.0	300.0	282.00
MW7S	345.0	174.0	313.0		277.33
MW8S	1.0	3.0			2.00
MW9S	4,100.0	248.0	1,310.0		1,886.00
MW10S	60.3	16.8	115.0		64.03
MW11S	4.6	4.3			4.45
MW12S	17.0	13.1	22.1		17.40
MW13S	31.8	31.0	157.0	143.0	90.70
MW14S	90.4	63.5	79.0		77.63
MW15S	4.9	2.2			3.55

Sample	Arsenic (mg/kg)	MW1S	MW3S	MW4S	MW5S	MW6S	MW7S	MW8S	MW9S	MW10S	MW11S	MW12S	MW13S	MW14S	MW15S
TT0301	360						360		360						
TT03W01	236	236					236		236						
TT03W02	20.6	20.6													
TT0602	0.92					0.92									
TT0604	6.5					6.5									
TT0701	1820								1820						
TT08A01	304								304						
TT1001	191								191						
TT1402	38							38	38	38					
TT2502	115						115		115						
TT2503	1720						1720		1720						
P10706	10.1					10.1									
PW0107	161								161	161					
SB0702	54.9						54.9								
SB0704	37.4						37.4								
SB0708	9.2						9.2								
SB0807	1.9							1.9							
SB0903	761								761						
SB0909	50.4								50.4						
SB1003	1.5									1.5					
SB1007	5.2									5.2					
SB1404	4.7													4.7	
SB1408	6.9													6.9	
SB1508	2.5														2.5
SB1602	14.3													14.3	
SB1604	16.7													16.7	
SB1608	9.5													9.5	
SB1702	41.2													41.2	
SB1704	156													156	
SB1708	9.3													9.3	
SB1802	41.5													41.5	
SB1804	9.4													9.4	
SB1808	4.5													4.5	
SB1902	67.2		67.2											67.2	
SB1904	24.9		24.9											24.9	
SB1908	3.8		3.8											3.8	
SB2002	104						104								
SB2004	22.3						22.3								
SB2008	7.7						7.7								
SB2009	6.1						6.1								
SB2102	157						157								
SB2104	20.7						20.7								
SB2108	6.2						6.2								
SB2202	36.5						36.5								
SB2204	3.3						3.3								
SB2208	6.7						6.7								
SB2302	92						92								
SB2304	51.2						51.2								
SB2308	7.1						7.1								
SB2402	12.2	12.2													
SB2404	8.5	8.5													
SB2408	6.6	6.6													
SB2502	7.6	7.6													
SB2504	7.9	7.9													
SB2508	2.6	2.6													
SB2602	233	233													
SB2604	12.1	12.1													
SB2608	3.2	3.2													
SB2702	4.1	4.1													
SB2704	4.4	4.4													
SB2708	6	6													
SB2802	5.4					5.4									
SB2804	0.7					0.7									
SB2808	5.6					5.6									
SB2902	12.6					12.6									
SB2904	6					6									
SB2908	8.5					8.5									
SB3003	9.8				9.8										
SB3007	3.5				3.5										
SB3009	1.4				1.4										
SB3103	6				6										
SB3107	1.6				1.6										
SB3202	8								8						
SB3204	6.6								6.6						
SB3208	7.4								7.4						

Table 3C-2
Average Well-Specific Arsenic Concentrations in Soil
Waukegan Manufactured Gas & Coke Plant Site

Sample	Arsenic (mg/kg)	MW1S	MW3S	MW4S	MW5S	MW6S	MW7S	MW8S	MW9S	MW10S	MW11S	MW12S	MW13S	MW14S	MW15S
									Representative Well(s)						
SB3302	620								620						
SB3304	23.5								23.5						
SB3308	21.8								21.8						
SB3402	170								170						
SB3404	160								160						
SB3408	42.7								42.7						
SB3502	104								104						
SB3504	16.3								16.3						
SB3508	3.2								3.2						
SB3602	20.9			20.9											
SB3604	12.7			12.7											
SB3608	2.5			2.5											
SB3702	3.1			3.1											
SB3704	2.5			2.5											
SB3708	2.9			2.9											
SB3802	26.4			26.4											
SB3804	23.3			23.3											
SB3808	6			6											
SB3902	21.8			21.8					21.8	21.8					
SB3904	2.3			2.3					2.3	2.3					
SB3908	3.9			3.9					3.9	3.9					
SB4002	25.3								25.3	25.3					
SB4005	4.9								4.9	4.9					
SB4008	5								5	5					
SB4102	29.5									29.5					
SB4104	5.3									5.3					
SB4108	10.2									10.2					
SB4202	56.2									56.2					
SB4204	6.5									6.5					
SB4208	6									6					
SB4302	1.1									1.1					
SB4304	6									6					
SB4308	5.2									5.2					
SB4402	5.5									5.5					
SB4404	5									5					
SB4408	10.3									10.3					
SB4502	15.7									15.7					
SB4504	3.6									3.6					
SB4508	4.8									4.8					
SB4605	2.8							2.8							
SB4608	4.7							4.7							
SB4702	29							29							
SB4704	1.6							1.6							
SB4708	7.6							7.6							
SB4802	5.9							5.9							
SB4804	1.8							1.8							
SB4808	0.4							0.4							
SB4902	1.3							1.3							
SB4904	1.4							1.4							
SB4908	1.5							1.5							
SB5002	4.4									4.4					
SB5004	3.2									3.2					
SB5008	2.7									2.7					
SB5104	2.4														
SB5109	2.5														
SB5205	1.7														
SB5208	3.8														
SB5304	2														
SB5502	11							11		11					
SB5902	1.2									1.2					
SB5904	2.7									2.7					
SB5908	3.1									3.1					
SB6002	33.6		33.6				33.6								
SB6004	63		63				63								
SB6008	11.5		11.5				11.5								
Average		40.34	34.00	10.69	4.46	6.26	143.70	7.78	245.38	14.63	0.00	0.00	0.00	29.28	2.50

Table 3C-3
Regression Correlation for Soil and Groundwater Concentrations
Waukegan Manufactured Gas & Coke Plant Site

Regression Output:

Constant		0.0000
Std Err of Y Est		0.0301
R Squared		0.9062
No. of Observations		7.0000
Degrees of Freedom		6.0000
X Coefficient(s)	0.0021	
Std Err of Coef.	0.0002	

Table 3-C-4

Target Soil Concentrations for Protection of Groundwater
Waukegan Manufactured Gas and Coke Plant Site

Parameter	Soil to Groundwater Concentrations		
	Generic SSL Illinois Taco Class I (mg/kg) [1]	Illinois TACO Class II (mg/kg)	Site Specific Based on Class I (mg/kg)
Carcinogenic PAHs			
Benzo (a) anthracene	2	8	16
Benzo (b) fluoranthene	5	25	49
Benzo (k) fluoranthene	49	250	490
Benzo (a) pyrene	8	82	82
Carbazole	0.6	2.8	5
Chrysene	160	800	1,590
Ideno (1,2,3, cd) pyrene	14	69	140
Non-Carcinogenic PAHs			
Fluorene	560	2,800	5,500
Naphthalene	84	420	800
Organics			
Phenol	100	100	270
Benzene	0.03	0.17	0.13
PCBs	1	10	62
Inorganics (pH 7.0)			
Arsenic	29	120	NA
Cadmium	11	110	NA
Cyanide	40	120	NA
Mercury	3.3	16	NA

Note:
[1] Dilution attenuation factor of 20
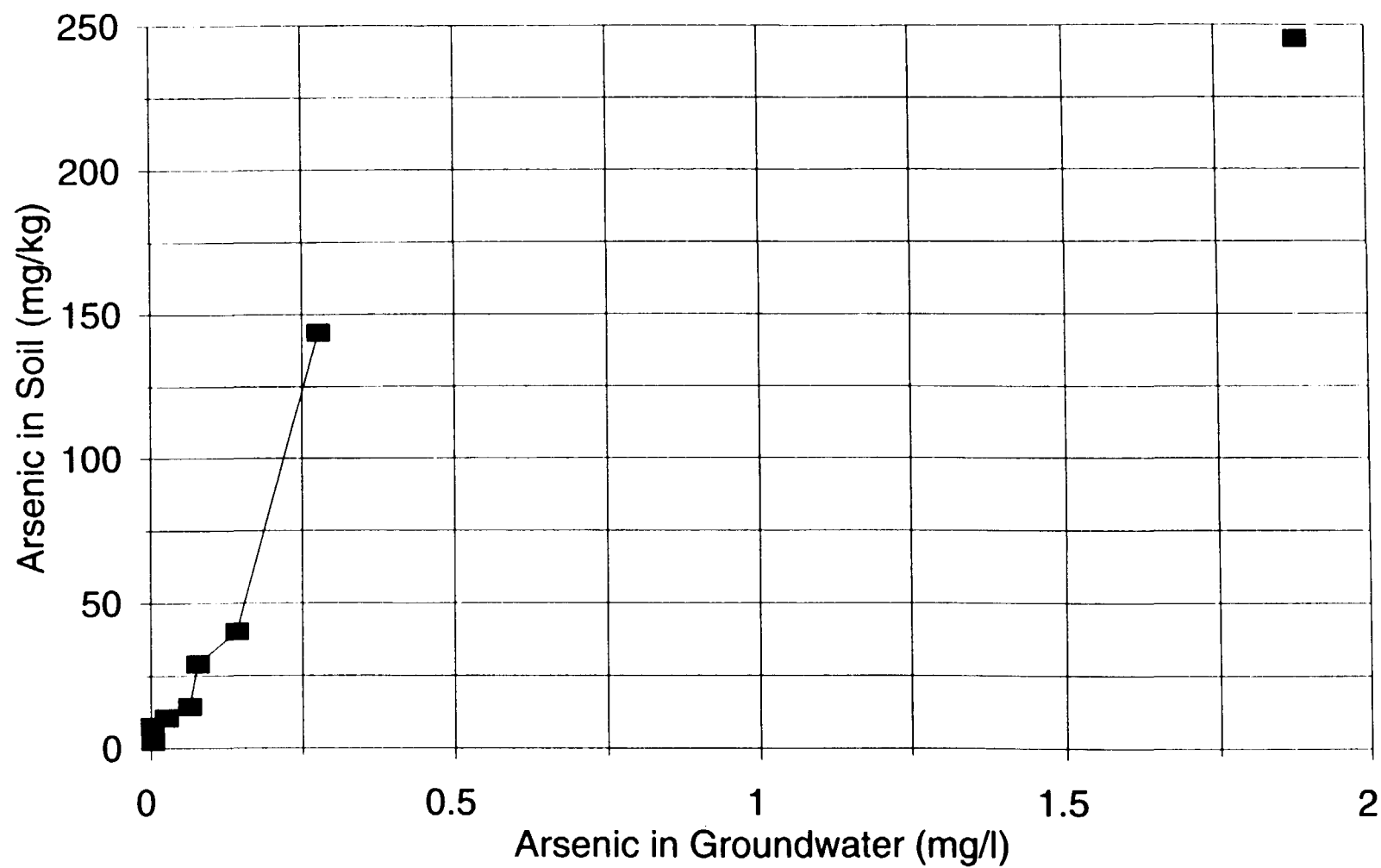
Figure 3-C-1

CORRELATION OF ARSENIC CONCENTRATIONS
Waukegan Manufactured Gas & Coke Plant Site

Appendix 3-D

Revised Risk Calculations
for Fish Consumption

Appendix 3-D

Revised Risk Calculations for Fish Consumption

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Appendix 3-D

Revised Risk Calculations for Fish Consumption

This appendix presents the calculations used to estimate the potential risks associated with current or future subsistence fishing exposures.

For the subsistence fishing exposure scenario under the RME approach, the HHRA used upper-bound values for exposure frequency (EF = 365 days/yr); exposure duration (ED = 30 years); and the daily fish ingestion rate (IR = 132 grams/day); and assumed all fish consumed were equally contaminated. Use of these upper-bound values resulted in an estimated risk of 3 x 10^{-6} as shown in Table 3-D-1.

However, in the U.S. EPA's final water quality guidance for the Great Lakes system, a fish ingestion rate of 15 grams per day is used. This value represents a "Great Lakes specific" fish consumption rate, which the EPA said "will provide adequate health protection for the public, including more highly exposed sub-populations" (March 23, 1995, 60 FR, 15365). Using this revised value for fish consumption lowers the overall risk due to fish consumption as noted in Table 3-D-1.

Finally, the U.S. EPA's value of 30 years for the exposure duration is conservative in comparison to other values in the literature. Using a more median value for the exposure duration lowers the calculated risk even further as shown in Table 3-D-1.

Table 3D-1
Revised Risk Calculations for Fish Consumption
Waukegan Manufactured Gas and Coke Plant Site

Parameter	Slope Factor (mg/kg-day)-1	Calculated Risk		
		HHRA Values	GLI Consumption	CTE Exp.Duration
Arsenic	1.5	2.67E-06	3.03E-07	8.08E-08
Benzene	0.029	2.16E-07	2.45E-08	6.53E-09
Total Risk		2.88E-06	3.28E-07	8.74E-08

Risk Equation:
Risk=Intake(g/kg-day)*1000(mg/g)*Slope Factor(mg/kg-day)-1

Intake Equation
(CxCFxCRfxFIxEFxED)/(BWxATx365days/yr)

			HHRA Values	GLI Consumption	CTE Exp.Duration
Intake Parameters					
C	Concentration in Fish (ug/kg)				
	Arsenic		2.2	2.2	2.2
	Benzene		9.2	9.2	9.2
CF	Conversion Factor (10E-9 kg/ug)		1E-09	1E-09	1E-09
CRf	Fish Ingestion (g/day)		132	15	15
FI	Fraction ingested from site (unitless)		1	1	1
EF	Exposure Frequency (meals/yr)		365	365	365
ED	Exposure Duration (years)		30	30	8
BW	Body Weight (kg)		70	70	70
AT	Averaging Time (yrs)		70	70	70

Appendix 4-A

Preliminary Evaluation of Effectiveness of Proposed Vadose Zone Soil Remediation

Appendix 4-A

Preliminary Evaluation of Effectiveness
of Proposed Vadose Zone Soil Remediation

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Appendix 4-A

Preliminary Evaluation of Effectiveness of Proposed Vadose Zone Soil Remediation

1.0   Introduction

As discussed in Section 4.3.1, the soil remediation zones include visually-delineated PAH Remediation Zones and the pre-defined Arsenic Remediation Zone, as depicted in Figure 4-A-1. These delineations are intended to satisfy the soil Remedial Action Objectives (RAOs) at the WCP site.

This appendix has two objectives:

1. Present a confirmation process for the evaluation of soil removal plans in order to ensure the attainment of soil RAOs; and

2. Present a preliminary evaluation of the effectiveness of the delineated soil remedy.

A common element in the above discussion is the representative exposure concentration (REC), which is described in Section 2 of this appendix. Section 3 of this appendix presents the outline of the soil excavation confirmation process, while Section 4 of this appendix provides the preliminary results of the effectiveness of the delineated soil removal based on the analysis of the existing soil data.

2.0   Representative Exposure Concentration (REC)

As discussed in Section 3, soil Remedial Action Objectives (RAOs) at the WCP site are defined within the context of risk-based cleanup goals. Such risk-based remedial goals are intended to be compared to representative exposure concentrations (RECs) over specified exposure domains. These comparisons will ensure protectiveness of the remedy.

The REC is one of the key variables in estimating exposure in risk calculations. U.S. EPA *Risk Assessment Guidance for Superfunds, Volume 1. Human Health Evaluation Manual (Part A)*, Interim Final, EPA/540/1-89/002, 1989 (RAGS Part A) defines the REC as the arithmetic average of the concentration that is contacted over the exposure period.   U.S. EPA *Ecological Risk Assessment Guidance for Superfund: Process for Designing and Conducting Ecological Risk Assessments*,

Interim Final, EPA 540-R-97-006, June 1997 (Ecological RAGS) defines the representative concentration as the level of contaminant occurring at exposure. The representative concentration is also referred to as "the concentration term" in the intake equation.

The appropriate computation of RECs must incorporate the observed large variability of measured chemical data. Such variations are typical in contaminated sites, which have prompted U.S. EPA to recommend the use of statistical methods for computing representative concentrations.

The REC is not a point value but rather is a value associated with an exposure domain, i.e., an area over which the exposed population is likely to come into contact with a contaminant over the targeted exposure duration. The REC is conservatively estimated as the upper confidence limit of the arithmetic mean concentration (UCL), as described in USEPA *Supplemental Guidance to RAGS: Calculating the Concentration Term*, Publication 9285.7-08, May 1992. U.S. EPA *Methods for Evaluating the Attainment of Cleanup Standards, Volume 1: Soils and Soil Media*, Chapter 6 (Box 6.7), EPA230/02-89-042, 1989 (Cleanup Attainment Guidance) describes procedures to compute UCL, as

$$UCL = m + t_{1-\alpha, n-1} \frac{s}{\sqrt{n}}$$

where,

UCL	=	Upper confidence limit of the mean;
m	=	Arithmetic mean;
$t_{1-\alpha, n-1}$	=	Student's *t* value with an exceedance probability of α and *n-1* degrees of freedom;
s	=	sample standard deviation; and
n	=	number of samples.

At the WCP site, the attainment of soil RAOs will be assessed by computing UCL of constituents of concern over appropriate exposure domains centered around various remediation zones, consistent with the above U.S. EPA guidance. The extent of the exposure domains at the WCP site are discussed in the following subsection.

2.1 WCP Exposure Domains

As noted in Section 3.2.5, the appropriate exposure domain must be consistent with risk exposure scenarios and frequencies used in development of the soil remedial goals. Consistent with the HHRA (U.S. EPA, 1995a), an industrial/commercial exposure domain, within which a worker may spent her or his entire professional life (i.e. 25 years), is conservatively determined to be 5 acres. Recent development of a Geographical Information System (GIS) database for Waukegan area transportation study further confirms the appropriateness of the 5-acre exposure domain as a representative domain size under an industrial/commercial scenario, although the complete parcel database for Lake County is still being developed.

Figure 4-A-2 depicts the extent of the 5-acre exposure domains over the various soil remediation zones. This figure also shows available subsurface soil samples used in the preliminary evaluation of the effectiveness of the delineated remedy in attaining soil RAOs. Concentrations of benzo(a)pyrene are shown relative to RHE soil risk values at levels of 10^{-4}, 10^{-5} and 10^{-6}. Benzo(a)pyrene exceeded RHE standards more than any other parameter and was therefore used as an indication of risk exceedance.

For the sake of conservatism, Section 4 of this appendix also evaluates the effectiveness of the delineated soil remedy using smaller 2.5-acre exposure domains, as delineated in Figure 4-A-3. Under both exposure domain arrangements, the western portion of the site that is almost un-impacted by the soil remediation zone is viewed as a single exposure domain, as depicted in Figures 4-A-2 and 4-A-3.

3.0 Excavation Confirmation Process

The attainment of the soil cleanup goals will be evaluated based on the process defined in U.S. EPA *Methods for Evaluating the Attainment of Cleanup Standards, Volume 1: Soils and Soil Media*, Chapter 6, EPA230/02-89-042, 1989 (Cleanup Attainment Guidance). For this purpose, post-excavation confirmatory sampling will be collected and analyzed as described below. This section provides a summary of basic components of the confirmatory sampling.

Objective: The objective of the confirmatory sampling is to ensure that within each exposure domain, the subsurface soil REC of constituents of concern is less than their corresponding 10^{-4} RHE soil risk values, as determined in Section 3.

Confirmatory Sampling Procedure: The sampling will be conducted according to a statistically-based random procedure, involving the following steps:

- Step 1. Number of Confirmatory Sampling Points: On average, there will be one sample every 50 feet along the excavated perimeter of each soil remediation zone. For this purpose, the perimeter of each excavated zone will be measured. The measured perimeter length in feet will be divided by 50 feet and rounded to the nearest largest whole number. This value will be the number of confirmatory samples along the perimeter of the targeted excavated area. For small subsurface soil excavated area, there will be at least three samples.

- Step 2. Lateral Sampling Locations: A starting point along the excavated perimeter will be selected. This point will be randomly situated from the most southern corner of the excavated area in a counter-clockwise direction. Other lateral sampling locations will be situated uniformly with respect to the starting point along the perimeter of the excavated area.

- Step 3. Vertical Sampling Locations: Upon determination of the lateral location of a confirmatory sample along the excavated perimeter, the depth of that sample will be selected randomly along the subsurface soil excavation depth. Each sample will be representative of a one-foot segment of the wall, centered randomly at a 1, 2 or 3 foot depth along the excavated wall.

- Step 4. Chemical Analysis: Each confirmatory sample will be subjected to chemical analysis to determine concentrations of the constituents of concern.

- Step 5. Confirmation: The results of confirmatory soil data will be added to the existing subsurface data in each exposure domain. Using the expanded data set, subsurface RECs in each exposure domain will be computed as the 95% upper confidence limit of the mean concentration (95 UCL). 95 UCLs will be computed for each of the constituents of concern. In these computations existing data points within the excavated area will be assigned values equivalent to a one-half detection limit, or a representative concentration of the fill material if other than the clean fill. The computed subsurface soil RECs will be compared to the 10^{-4} RHE soil risk values, as determined in Section 3.

- Step 6. Excavation Expansion: In the event of a confirmatory failure, all or portions of the excavated perimeter will be expanded. These expanded portions will be treated as new

excavated areas, which will be subjected to confirmatory sampling procedures as described in Steps 1 through 5.

The above procedure provides a conservative process to confirm attainment of soil RAOs at the WCP Site.

4.0 Preliminary Evaluation of Delineated Soil Remedy

As a preliminary evaluation, the attainment of soil removal RAOs is simulated for each exposure domain. In these calculations, the existing data within each remediation zones are assigned values corresponding to the representative concentrations of the Designated Stockpile soil. Below-detection values are assigned values equal to one-half of the reported detection limits.

The corresponding values over the WCP exposure domains, as depicted in Figure 4-A-2, are listed in Table 4-A-1. The computed RECs indicate that the delineated removal actions not only will satisfy RHE risk values to 10^{-5}, but also meet the highly conservative RME risk values.

For the sake of conservatism, the RECs are also calculated for the smaller 2.5-acre exposure domains, as depicted in Figure 4-A-3. The corresponding RECs are listed in Table 4-A-2, which indicate that similar to the previous case, the delineated soil removals will surpass soil RAOs, even under the highly conservative RME scenario.

Due to the limited nature of the existing surface soil data, the effectiveness of the surface soil remedy is not numerically evaluated. However, Figure 4-A-4 clearly indicates that the existing surface soil, outside of the soil remediation zones, meets the soil RAOs, as discussed in Section 3. As a means for comparison, surface and subsurface arsenic samples are shown on Figure 4-A-5. As with benzo(a)pyrene, arsenic also meets soil RAOs.

5.0 Extent of Soil Remediation Zones Under More Stringent Risk Levels

The extent of the soil remediation zones is determined by the soil RAOs, as discussed in Section 3 of this FS. The above section provided preliminary evaluation of the delineated soil remediation zones based on the soil RAOs aimed at treating all soil that pose risks in excess of 10^{-4} risk levels under an industrial/commercial scenario. To further evaluate the reasonableness of the delineated

soil remediation zones, their extent has been computed under more stringent 10^{-5} and 10^{-6} risk levels using the conservative REM assumptions.

To attain cleanup under the above more stringent RAOs larger areas of the WCP soil has to be targeted for excavation and/or treatment. To determine the extend of the remediation zones under the more stringent risk levels, an iterative procedure consistent with the risk-based RAOs are pursued. For this purpose, extent of soil remediation zones are expanded, where their post-remedial REBS are computed, as described in the previous section.

Figures 4-A-6 and 4-A-7 display the expanded soil remediation zones that meet the requirements of the 10^{-5} and 10^{-6} REM risk levels, respectively. Figure 4-A-1 shows the current soil remediation zones, which as demonstrated in the previous section, will satisfy 10-4 REM risk levels. Figure 4-A-8 summarizes the effect of the selected risk levels on the volume of soil remediation zones. These results further confirm the effectiveness and reasonableness of the delineated soil remediation zones in Figure 4-A-1.

Table 4-A-1

5-Acre Exposure Domain RECs

Analyte	RME 10-4	RHE 10-4	Exposure Domains			
			1	2	3	4
Arsenic	268	20500	73.38	69.79	22.82	5.76
Benzo(a)anthracene	594	15000	5.50	14.22	7.14	4.80
Benzo(a)pyrene	59.4	1500	3.22	10.70	4.18	4.81
Benzo(b)fluoranthene	594	15000	4.56	12.28	5.73	5.77
DiBenzo(a,h)anthracene	59.4	1500	0.65	6.90	0.83	3.78
Indeno(g,h,i)pyrene	594	15000	1.28	8.06	1.69	4.22

All values shown in parts per million (ppm)

59101

Table 4-A-2

2.5-Acre Exposure Domain RECs

Analyte	RME 10-4	RHE 10-4	Exposure Domains						
			1 North	1 South	2 North	2 South	3 North	3 South	4
Arsenic	268	20500	67.30	92.58	129.39	36.34	43.42	12.10	5.76
Benzo(a)anthracene	594	15000	6.75	6.39	22.83	9.02	6.00	9.59	4.80
Benzo(a)pyrene	59.4	1500	3.52	3.94	18.04	5.09	3.57	5.55	4.81
Benzo(b)fluoranthene	594	15000	4.82	5.71	19.77	7.01	4.85	7.66	5.77
DiBenzo(a,h)anthracene	59.4	1500	0.71	0.77	13.37	0.91	0.87	0.96	3.78
Indeno(g,h,i)pyrene	594	15000	1.44	1.55	14.93	1.97	1.55	2.13	4.22

All values shown in parts per million (ppm)

200   0   200   400   600 Feet

LEGEND

Site Fenceline
Prop. Excavation Areas
Arsenic
PAH

Proposed Arsenic & PAH
Excavation Areas

Waukegan Manufactured Gas and Coke Plant
Waukegan, Illinois

Date	6-23-08		
File	WAUKG1S2	Figure	4-A-1

200   0   200   400   600   Feet

Subsurface BaP Results
With Excavation Areas &
5 Acre Domains

Waukegan Manufactured Gas and Coke Plant
Waukegan, Illinois

9-23-98

WAUKGIS2   4-A-2

1 North

1 South

2 North

2 South

3 North

3 South

4

LEGEND

Subsurface BaP
- Below RBL
- <1.6
- <1.5
- <2.4

Site Fenceline

Prop. Excavation Areas
- Arsenic
- PAH

2.5 acre Site Risk Zones

200   0   200   400   600 Feet

Subsurface BaP Results
With Excavation Areas &
2.5 Acre Domains

Waukegan Manufactured Gas and Coke Plant
Waukegan, Illinois

| | 4-23-08 | | |
| | WAUKGIS2 | | 4-A-3 |

1 North

1 South

2 North

2 South

3 North

3 South

4

LEGEND

Subsurface BaP
- Below RHI
- -10-6
- -10-5
- -10-4

Surface BaP
- Below RHI
- -10-6
- -10-5

Site Fenceline

Prop. Excavation Areas
- Arsenic
- PAH

2.5 acre Site Risk Zones

200   0   200   400   600 Feet

Surface & Subsurface BaP Results
With Excavation Areas &
2.5 Acre Domains

Waukegan Manufactured Gas and Coke Plant
Waukegan, Illinois

4-23-98

WAUKGIS2

4-A-4

Labels visible on the aerial image:
- 1 North
- 1 South
- 2 North
- 2 South
- 3 North
- 3 South
- 4

LEGEND

Subsurface Arsenic
- Below RHI
- -10-6
- -10-5

Surface Arsenic
- Below RHI
- -10-6
- -10-5

Site Fenceline

Prop. Excavation Areas
- Arsenic
- PAH

2.5 acre Site Risk Zones

200   0   200   400   600 Feet

Title: Surface & Subsurface Arsenic Results
With Excavation Areas &
2.5 Acre Domains

Project: Waukegan Manufactured Gas and Coke Plant
Waukegan, Illinois

Date: 9-25-08

File: WAUKGIS2

4-A-5

200   0   200   400   600 Feet

Approximate Extent of Soil
Remediation Zones Necessary
to Attain 10-5 RME Risk Level

Waukegan Manufactured Gas and Coke Plant
Waukegan, Illinois

LEGEND

Site Risk Zones
10-5 Excavation
Site Fenceline

200   0   200   400   600   Feet

Approximate Extent of Soil
Remediation Zones Necessary
to Attain 10-6 RME Risk Level

Waukegan Manufactured Gas and Coke Plant
Waukegan, Illinois

LEGEND

☐ Site Risk Zones
▨ 10-6 Excavation
Site Fenceline
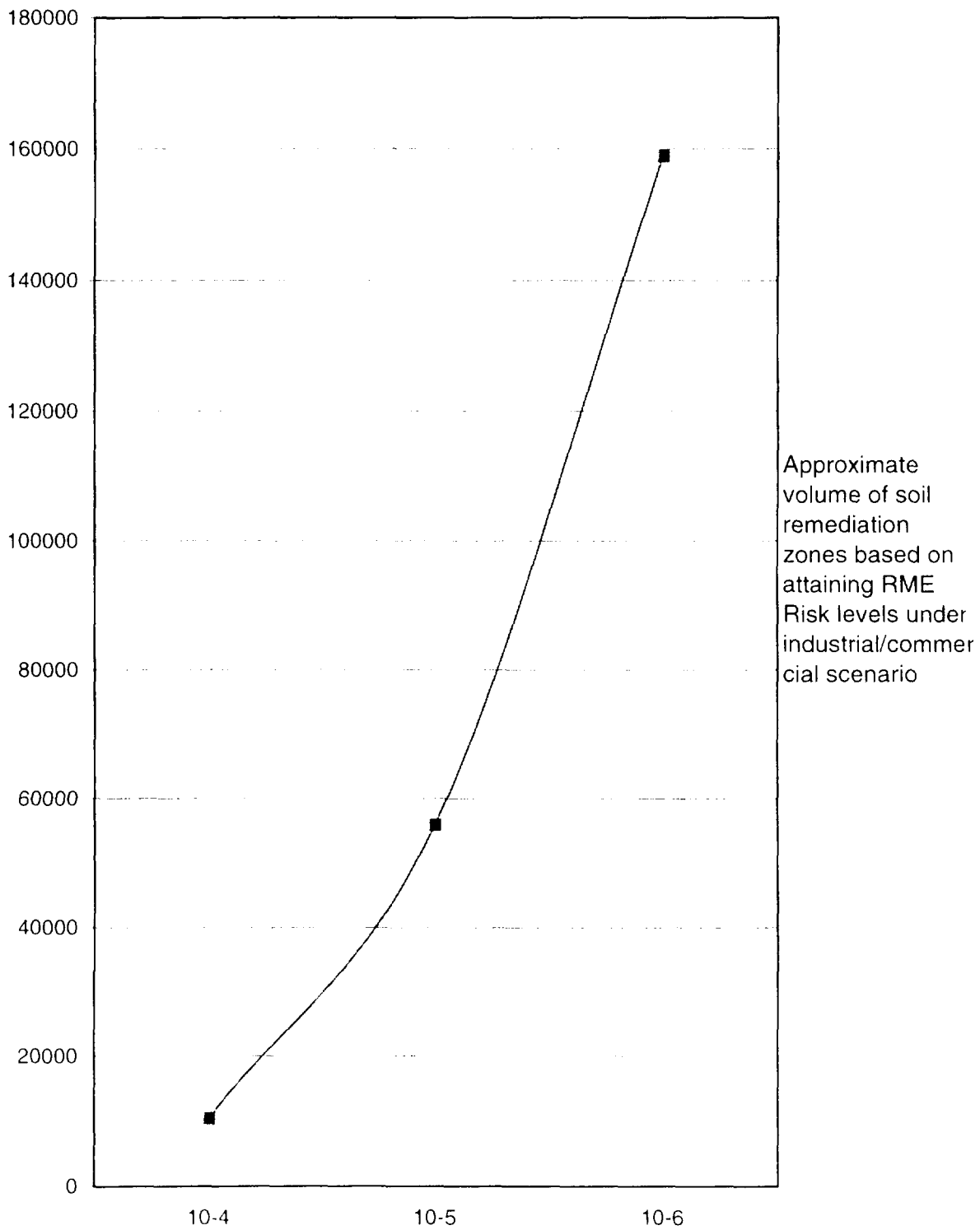
Figure 4-A-8

VOLUME OF SOIL ASSOCIATED WITH
RME RISK LEVELS
Waukegan Manufactured Gas & Coke Plant Site

Appendix 4-B

Preliminary Determination of
Groundwater Remediation Zone Selection

Appendix 4-B

Groundwater Treatment Zone Selection

List of Figures

Appendix 4-B

Groundwater Treatment Zone Selection

The analysis of groundwater discharge to surface water in Section 2 and Appendix 2-D showed that the discharge of site groundwater to surface water does not result in exceedance of surface water quality standards in those areas where Lake Michigan Basin water quality standards are applied (the harbor and breakwater areas). For groundwater discharging to the open waters of Lake Michigan directly east of the site (the Lake), a site-specific groundwater RAO to reduce the mass within the area of impacted groundwater will be applied as defined in this appendix.

The area of impacted groundwater is described in detail in Section 2. This work focuses on the area of impacted groundwater that discharges to the Lake. Within this area, the zone where mass reduction will be beneficial is defined by the proportion of COC mass addressed in relation to the effort expended. The COC mass proportion is measured as the percent of the total mass within the area of groundwater discharging to the Lake. The effort expended is measured by the areal extent of the action. This evaluation can be performed for arsenic, using Figure 4-B, a graph of the percent mass of arsenic versus area for the groundwater discharging to the lake. As the arsenic concentration falls from 40 mg/L to 20 mg/L, a 12 percent increment in area adds a 10 percent increment in mass. From 20 mg/L to 10 mg/L, a 32 percent increment in area yields only a 12 percent increment in mass. Because this represents a disproportionate level of effort for the potential benefit obtained, the potential target area for arsenic would be in the concentration range of 20 mg/L to 40 mg/L.

Figure 4-B-2 is a graph of the percent mass of total phenol versus area for the groundwater discharging to the lake. Applying the same procedure as for arsenic, the total phenol potential target area is at about 500 mg/L.

Figure 4-B-3 is a graph of the percent mass of ammonia versus area for the groundwater discharging to the lake. Again, applying the same procedure as for arsenic, the ammonia potential target area is between 500 mg/L and 1,000 mg/L.

In order to delineate the groundwater treatment zone, the estimated limits of the areas for each parameter are shown on Figure 4-B-4. The figure shows the groundwater divide for the area discharging to the lake. The areas exceeding 500 mg/L ammonia, 500 mg/L total phenols, and

20 mg/L arsenic are as shown. Where these three areas overlap will be the zone of greatest effectiveness for groundwater treatment. This is the preliminary groundwater treatment zone.

This delineation must be considered preliminary, as it is based on combining data from 1996 and 1997. The data density is sufficient to define potential concentration limits but is not sufficient to resolve concentration isopleth positioning. During remedial design, the delineation will be defined with additional data collection from this portion of the site. Additional investigation is likely to include sampling groundwater along a north-south transect on the beach.

For the purposes of defining the Groundwater Treatment Zone for this FS, the 20 mg/L arsenic contour was used. This area more than encompasses the preliminary groundwater treatment zone shown on Figure 4-B-4. Using the 20 mg/L arsenic contour also assures groundwater discharging to the breakwater area will be treated the same as groundwater discharging to the "open waters" area of the lake, and defines a zone adjacent to the new slip for groundwater treatment.

Review of the groundwater mixing model (Appendix 2-D) shows that groundwater discharging to the lake is not expected to produce exceedances of lake standards under average or high mixing conditions. (Although phenols are computed to exceed standards, natural attenuation mechanisms operate strongly on phenol so that it is unlikely to cause exceedances.) Appendix 2-D suggest there is the potential for exceedances of the ammonia standard under low mixing conditions in the absence of remedial action. Remedial actions have a significant effect on the mass flux of ammonia to the lake, as explained in Appendix 5-D. Thus, implementing a groundwater remedy will significantly reduce the likelihood of ammonia standard exceedances in the lake adjacent to the site.

Percent Mass of Arsenic within Area
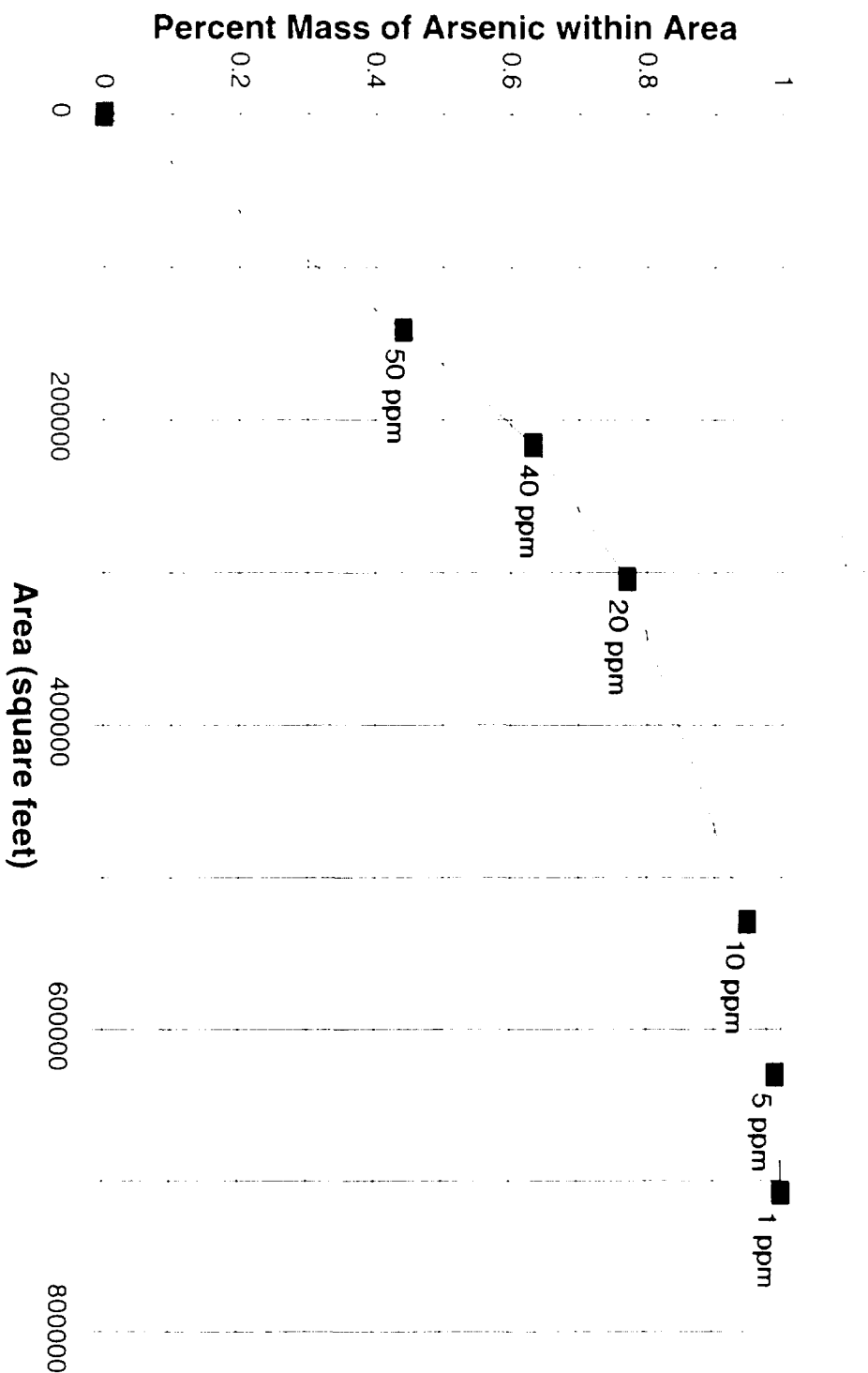
Figure **4-B-1**

PERCENT MASS OF ARSENIC vs. AREA

LAKESIDE

Waukegan Manufactured Gas and Coke Plant Site

Percent Mass of Total Phenol in Area

0   0.2   0.4   0.6   0.8   1

0

100000

200000

1000 ppm

300000

Area (square feet)

400000

500 ppm

500000

100 ppm

600000

1 ppm

700000
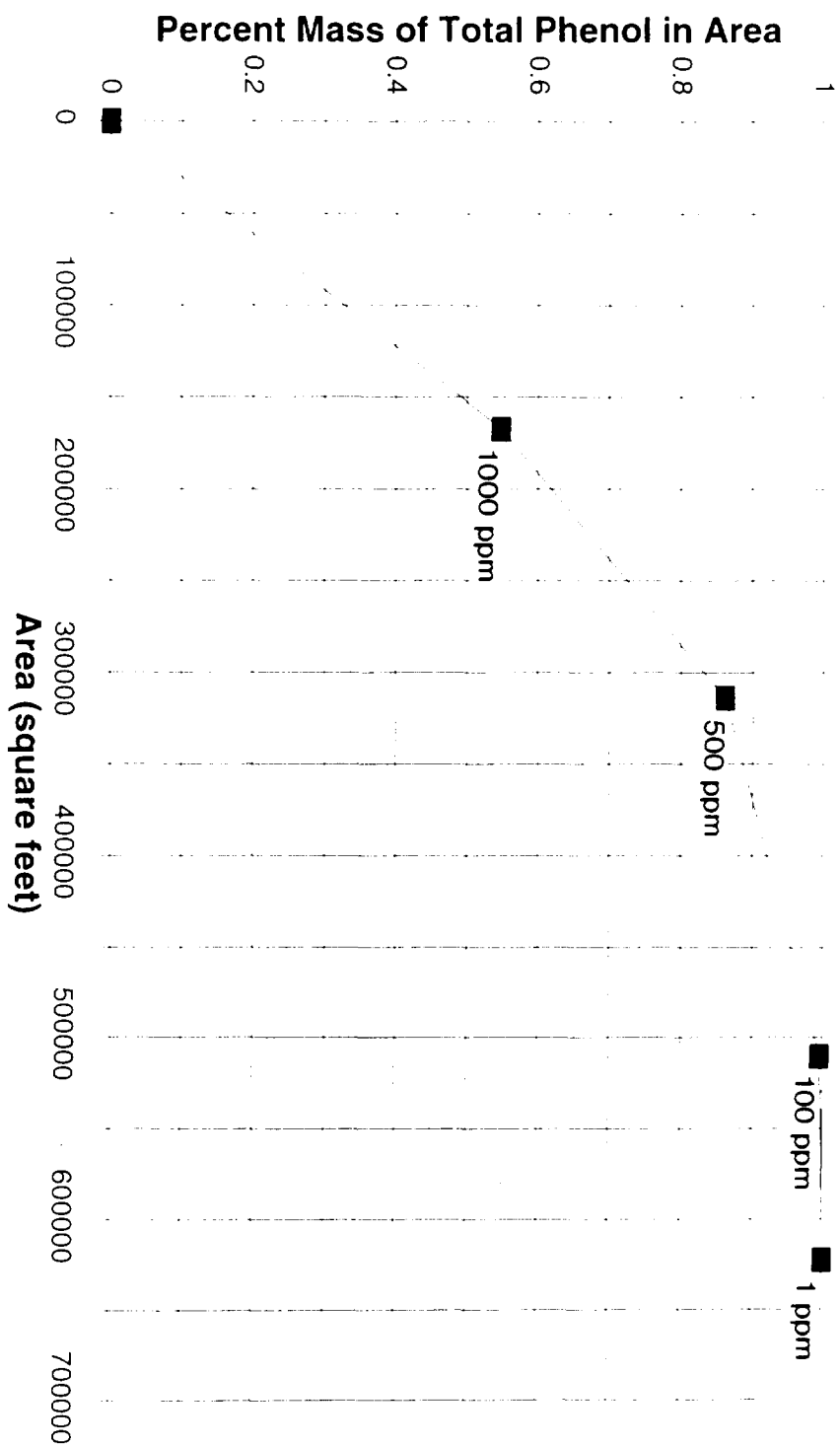
Figure 4-B-2

PERCENT MASS OF TOTAL PHENOL vs. AREA
LAKESIDE
Waukegan Manufactured Gas and Coke Plant Site
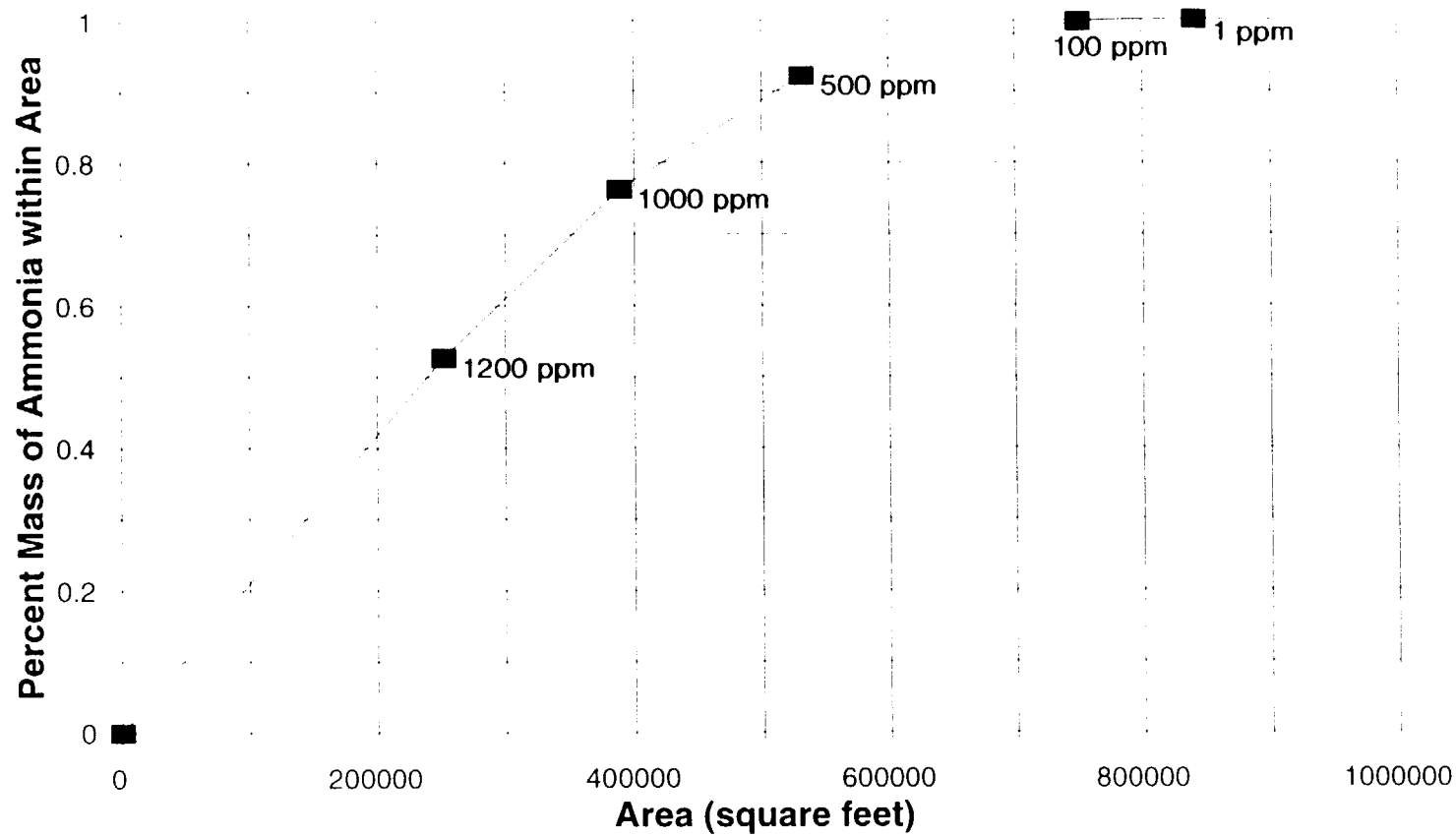
Figure 4-B-3

PERCENT MASS OF AMMONIA vs. AREA
LAKESIDE
Waukegan Manufactured Gas and Coke Plant Site

0   400

SCALE IN FEET

SB-64

SB-52

SB-53

SB-54

SB-63

PUBLIC BEACH

SB-62

SB-61

MW-13

MW-12

MW-14

OUTBOARD MARINE COMPANY PLANT NO. 2

500

Pershing Road (Sea Horse Drive)

MW-7

GROUNDWATER DIVIDE

MW-4

MW-8

MW-9

MW-15

MW-3

OUTBOARD MARINE COMPANY PLANT NO. 1

MW-1

MW-10

LARSEN MARINE

MW-11

SLIP NO. 4 (NEW SLIP)

MW-6

MW-5

WAUKEGAN HARBOR

JMW 9654_1DWG 400.00 10/27/1998 14.14.00
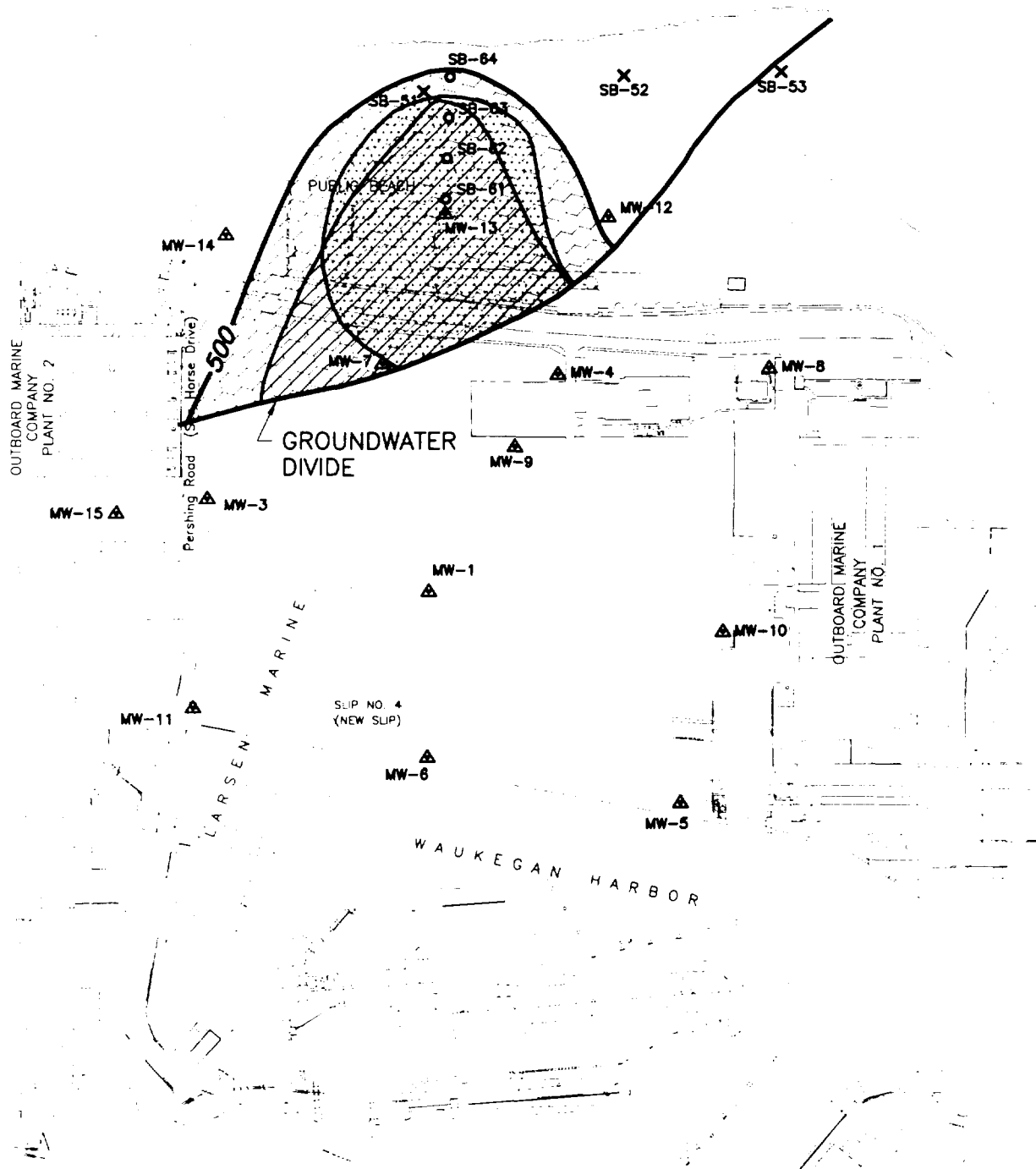
LEGEND

☐	500 mg/L AMMONIA
▨	500 mg/L TOTAL PHENOLS
░	20 mg/L ARSENIC

Figure 4-B-4

PRELIMINARY GROUNDWATER
TREATMENT ZONE SELECTION
(Concentrations In mg/L)
Waukegan Manufactured Gas
And Coke Plant Site

Appendix 4-C

Description of Remedial Technologies and Process Options

Appendix 4-C

Description of Remedial Technologies and Process Options
Vadose Zone Soils

No Action

The no-action alternative constitutes the absence of any remedial actions. No action is considered as a baseline for comparison to all other potential remedial actions as required by the Contingency Plan (40 CAR 300.430[e][6]).

Routine Monitoring

Routine monitoring consists of periodic sampling of soils during implementation of a remedy. Routine monitoring may be used to determine changes in contaminant distribution over time, evaluate treatment performance, or determine the integrity of access and development use restrictions.

Institutional Controls (Access/Use Restrictions)

Access restrictions, such as fences, gates, plantings, or other physical barriers, are intended to limit contaminant exposure. Development restrictions reduce or eliminate contaminant exposure by limiting the scope of work on the property (e.g., limiting building construction to slab-on-grade; requiring personal protective measures for subsurface work).

Containment

Containment systems are designed to prevent migration of impacted media. These systems include both horizontal and vertical barriers. Although vertical barriers are not effective for soil remediation at the WCP site, they are considered for groundwater remediation and discussed in groundwater response actions. Horizontal barriers that may be effective for site soils include caps as discussed below.

Cap

A horizontal barrier or cap is placed over contaminated soils to minimize infiltration of precipitation through the vadose zone. Caps reduce or eliminate exposure to surface soil by dermal contact and ingestion. The suitable caps for the WCP site include a soil cover, asphalt cap, low permeability cap and phytoremediation cap

Soil Cover

A layer of soil and vegetation is placed over the contaminated area, encouraging runoff by providing a sloped surface and enhancing evapotranspiration, to reduce the net infiltration.

Asphalt Cap

Continuous asphalt or bituminous asphaltic concrete caps are placed over graded areas. Suitable subbase may be required if existing soils are not appropriate from an engineering standpoint.

Low-Permeability Cap

Low-permeability caps employ the use of clay or synthetic membranes to reduce water infiltration and exposure to surface soils. Clay caps are installed by: (1) grading the site, (2) applying a compacted clay layer over the contaminated area, (3) covering the clay with topsoil, and (4) establishing vegetation to prevent excessive moisture loss and reduce erosion. Similarly, synthetic membranes are installed by: (1) subbase grading, (2) placement of a clean fill layer, (3) membrane placement, and (4) placement of a topsoil layer to protect the membrane and sustain vegetative growth.

Phytoremediation Cap

A phytoremediation cap consists of a cover of selected trees, shrubs, and native grasses. Within the Midwest region, selected trees for PAH-impacted soils include hybrid poplar, eastern red cedar, black locust, mulberry, and Osage orange. Shrubs and native grasses could provide ground cover. Establishing a tree cover may take eight to ten years depending on the species of tree.

The plants restrict the offsite movement of water-soluble contaminants by (1) reducing leaching by water removal through plant transpiration, (2) immobilization through binding to organic root material, (3) degradation by root-stimulated microflora, (4) plant uptake and metabolism, and (5) prevention of soil and wind erosion. Phytoremediation caps may also limit pedestrian access to an area.

Excavation and Disposal

Excavated soils can be placed in a controlled facility. This approach minimizes further migration of contaminants. Controlled facilities include onsite and offsite landfills or vaults.

Onsite Disposal

Excavated soil can be placed in an onsite vault or other secure containment cells for long-term storage. This method of disposal isolates the waste from groundwater. Typical vault construction consists of: (1) a liner system composed of two layers of synthetic membrane over a clay base, (2) a leachate collection system over the primary liner, (3) a leak detection system between the primary and secondary liner, and (4) a synthetic membrane or clay cap over the contaminated soil.

Offsite Disposal

Offsite disposal facilities include RCRA Subtitle D landfills, RCRA Subtitle C landfills, and industrial landfills. The transported waste must meet the specifications of a landfill, and thus, may require pretreatment. In general, Subtitle D landfills are solid waste (municipal) landfills and accept only non-hazardous waste. Subtitle C landfills may accept hazardous waste; however, pretreatment in accordance with land disposal regulations may be required for disposal.

Excavation and Treatment

Excavated soil can be processed on- or off-site through a treatment system. On-site treatment requires an adequate area for storage and treatment of excavated soil. Off-site treatment is conducted at approved treatment facilities.

Treatment technologies include physical, chemical, or biological removal of contaminants from the soil matrix. Process options for treatment of soils ex-situ include land treatment, composting, biopile, thin spreading, aeration, bioslurry reactor, soil washing, stabilization/solidification, low-temperature thermal desorption, solvent extraction, incineration, vitrification, cement kiln incineration/fuel blending, and chemical oxidation.

Biological Treatment

Biological treatment of organic contaminants is achieved through enhancement of the activities of existing microorganisms in the soil. Process options for ex-situ biological treatment include land spreading or composting, biopile, and bioslurry reactor.

Land Spreading/Composting

Land spreading or composting technology biodegrades organic constituents in contaminated soil in an aboveground treatment facility.

Thin spreading is essentially a mass transfer technology whereby the organic compounds in a thinly spread soil layer on the ground surface volatilize. Photodegradation and increased natural biodegradation also occurs.

The biodegradation and stabilization of organic fractions by composting depends on the optimal interaction of temperature, oxygen, moisture, and the carbon/nitrogen/phosphorous ratio. Composting relies on the microbial activities to decompose organic material into more stable, humus-like substances. This technology has been demonstrated as technically feasible for removing PAHs and petroleum from soils. Removal of PAH compounds occurs at a much slower rate than petroleum compounds.

The most common methods of composting are windrow methods, static pile, and vertical systems. In all methods, a bulking material is added to the contaminated soils or sludge to provide structure or porosity, adjust the moisture content of the mass, and adjust the carbon/nitrogen ratio. The mixture is either spread (windrow) or piled (static pile) or placed into some type of containment vessel (vertical system). All these options require aeration and leachate management.

Biopile

Biopile refers to the technology of biodegrading organic constituents in soils or sludges in a covered or uncovered pile. The pile may have conduits for nutrient distribution and venting. This technology has been proven effective for the removal of PAHs and petroleum compounds.

Bioslurry Reactor

A bioslurry reactor consists of continuously stirred reactors that allow the soil to be mixed into a slurry of soil and water. In a reactor, it is easier to control nutrient addition and air venting. This optimizes the contact of microorganisms with organic compounds. This technology has been proven effective for the removal of PAHs and petroleum compounds.

Physical/Chemical Treatment

Physical treatment includes processes that can physically separate or treat contaminants.

Soil Washing

Soil washing is a water or solvent-based process to remove contaminants, including volatile organic compounds and petroleum residues. The process removes contaminants from soils

in one of two ways: (1) by dissolving or suspending contaminants in the wash solution; or (2) by concentrating contaminants into a smaller volume of soil through particle size separation techniques similar to those used in mineral processing operations.

The concept of reducing soil contamination through particle size reduction relies on the tendency of most organic and inorganic contaminants to bind, either chemically or physically, to clay- or silt-sized soil particles. The silt and clay, in turn, are attached to sand and gravel particles by physical processes, primarily compaction and adhesion. Washing processes that separate the fine clay and silt particles from the coarser sand and gravel particles effectively separate and concentrate the contaminants into a smaller volume of soil that must then be further treated by another technology. Therefore, soil washing is often used as a preprocessing step in reducing the quantity of material to be treated by subsequent processes. Soils containing a large amount of clay and silt typically do not respond well to soil washing, especially as a stand-alone technology.

Stabilization/Solidification

Stabilization/solidification utilizes reagents to facilitate a chemical or physical reduction of the mobility of the contaminant. The reagent is mixed with the contaminated soil using either a mixing vessel, mixing lagoon, or pit and allowed to cure. This technology is primarily effective for immobilizing metals and inorganics and has more recently been found to be effective for organic-contaminated soil.

Thermal Desorption

Low-temperature thermal desorption uses elevated temperatures (approximately 800°F to 1000°F) to volatilize organic contaminants from the soil. The organic compounds are then destroyed in an afterburner at temperatures of approximately 1400°F or higher. The air stream is then discharged through a stack. The end product is a dry soil containing trace amounts of the organic residual (predominantly heavier, nonvolatile, immobile compounds) that is not volatilized off the soil. This technology is in widespread use for the treatment of petroleum-contaminated soils and is demonstrated for PAH-contaminated soil.

Solvent Extraction

Solvent extraction uses a liquid solvent for leaching a soluble substance from a solid matrix. Generally used as one of a series of unit operations, solvent extraction reduces the volume of hazardous waste to treat by separating out the contaminants from solids, sludges, and sediments. This can reduce overall cost for managing a site. This process is

suitable for organic wastes but generally not applicable for treating inorganics and metals. The technology uses water or water with wash-improving additives.

Incineration On-Site or at a RCRA Facility

Incineration uses high temperatures to heat the contaminated soil and volatilize and destroy the contaminants contained on the soil. Although there are several types of incinerators, the principle is basically the same for all types. The entire contaminated soil matrix is heated to approximately 1500° F and the contaminants are driven off and destroyed. The end product is a dry soil with trace amounts of the organic residual. The higher temperatures provided by incineration are typically not necessary to destroy contaminants typically associated with petroleum-contaminated soils.

Co-Burning at Power Plant

Co-burning soil and/or tarry material includes transportation of the soil material to a power plant. The power plant is able to burn coal tar related waste because of an exemption in the regulations. The coal tar waste is mixed with coal and burned as a supplemental fuel at the power plant.

Vitrification

Vitrification is based on the concept of joule-heating to electrically melt soil or sludge. Melt temperatures, in the range of 1600°C to 2000°C, act to destroy organic pollutants by pyrolysis. Inorganic pollutants are immobilized within the vitrified mass. Both the airborne organic and inorganic combustion by-products are collected in a negatively pressurized hood that draws the contaminants into an off-gas treatment system that removes particulates and other pollutants of concern.

Cement Kiln Incineration/Fuel Blending

Cement kiln incineration and/or fuel blending involves transportation of soil and/or tarry material using the waste as a supplemental fuel in the production of cement. Tar material would be excavated from the site and either used in its semi-solid state or transformed into a pumpable form (a process called liquification) and burned as a fuel at a cement kiln facility located at an off-site location. Management of the waste as a solid or liquefied blend is dependent on the particular technology offered by the fuel blending company.

Chemical Oxidation

Oxidation adds chemical compounds to oxidize organic contaminants and liberate free oxygen. The presence of heat and a catalyst may enhance its effectiveness. The most common oxidizing agents are hydrogen peroxide and ozone; catalysts may include metals such as iron, aluminum, and copper. Ultraviolet radiation can enhance the oxidation process. The presence of photosensitive material can significantly enhance the oxidation of highly halogenated organic compounds (U.S. EPA, 1992b).

In-Situ Treatment

In-situ treatments are processes which treat contaminated soils in place without excavation or other extractive techniques. In-situ options include aerobic bioremediation, phytoremediation, bioventing, stabilization/solidification, soil/solvent flushing, vapor extraction, thermal oxidation, and vitrification.

Biological Treatment

Biodegradation is the oxidation of organic matter by microorganisms. Microorganisms either metabolize the organic contaminants or the contaminants are transformed into other organic compounds via co-metabolism processes.

Aerobic Bioremediation

In-situ biodegradation stimulates the metabolism of naturally occurring soil microorganisms to degrade petroleum hydrocarbons to carbon dioxide, water, and humus. Microorganism stimulation is achieved by providing oxygen and nutrients. This process may also involve introducing cultured bacterial strains and adjustment of soil moisture, pH, and temperature. There are several methods of providing oxygen and nutrients to the soil.

Potential treatment levels range from low to high, depending on the wastes present and the suitability of the site and soil for maintenance of aerobic conditions. This technology is best suited to sandy soils. Soils with a low permeability, low pH, and variable soil conditions may lead to inconsistent or hindered biodegradation.

Phytoremediation

Phytoremediation caps consist of a cover of selected trees, shrubs, and native grasses. The plants restrict the off-site movement of water soluble contaminants by (1) reducing

leaching by water removal through plant transpiration, (2) immobilization through binding to organic root material, (3) degradation by root stimulated microflora, (4) plant uptake and metabolism, and (5) prevention of soil erosion.

Bioventing

In situ bioventing is a venting system to enhance bioremediation of organic compounds. Horizontal or vertical wells or vent points or lines are installed to transfer air to the soil by pumping air. The increased circulation of air enhances bioremediation of organic compounds. Nutrients may be added to the system.

Physical/Chemical Treatment

Physical/chemical treatment includes processes that can treat contaminants through chemical reactions.

Stabilization/Solidification

This technology reduces the mobility of soil contaminants. Deep soil mixing techniques can be used for in-situ stabilization/solidification. Stabilizing agents are applied directly to the contaminated soil and blended using mixing paddles or augers. Upon completion of the process, continuous stabilized mass is left behind. The depth of treatment by this technology is limited by the depth to bedrock. VOC compounds are typically not immobilized with this technology but are instead driven off by the heat of reaction during the process.

Soil/Solvent Flushing

In-situ flushing is similar to biotreatment, except that surfactants and/or polymers are added through upgradient injection wells to remove contaminants that adhere to the surface of soils. Downgradient groundwater, which contains surfactants, polymers, and contaminants, must be collected and treated. Caution must be taken against migration along uncontrolled pathways.

Vapor Extraction

Soil vapor extraction systems recover volatile contaminants from unsaturated soils by extracting air via a vapor recovery well. The process involves the use of vacuum pumps and a series of vertical or horizontal wells. The system operates by applying a vacuum through a piping system to the wells, which are sealed at the surface. The vacuum established in the soil draws the vapor-phase volatile organic compounds from the soil

pores and draws fresh air from the soil surface into the vadose zone. The removed volatile organic vapors are processed through a liquid-vapor separator prior to treatment or direct discharge to the atmosphere. Treatment units may consist of activated carbon beds, catalytic converters, or afterburners. The surface is usually sealed with a liner to prevent air short-circuiting and infiltrating rainwater. Sealing the surface also forces air to be drawn from a greater distance and ultimately contact a greater volume of soil.

Thermal Oxidation

The thermal blanket system consists of an insulated thermal blanket with heaters and a vapor extraction system. The vapor extraction system is operated at a negative pressure to collect and prevent off-gas emissions, reduce upward heat loss, and eliminate odor. The effectiveness of this process has been demonstrated at full-scale for removal of organics from vadose zone soil.

Vitrification

In-situ vitrification is based on the concept of joule-heating to electrically melt soil or sludge. Melt temperatures, in the range of 1600°C to 2000°C, act to destroy organic pollutants by pyrolysis. Inorganic pollutants are immobilized within the vitrified mass. Both the airborne organic and inorganic combustion by-products are collected in a negatively pressurized hood that draws the contaminants into an off-gas treatment system to remove particulates and other pollutants of concern.

Groundwater

No Action

The no action alternative constitutes the absence of any remedial actions. No action is retained as a baseline for comparison to all other potential remedial actions as required by the NCP.

Routine Monitoring

Groundwater and surface water monitoring consists of periodic sampling and analysis to evaluate temporal changes in water quality and the potential for offsite migration.

Institutional Controls (Access/Use Restrictions)

Institutional controls involve placing a legal restriction on placement of water supply wells or water use. Existing ordinances, rules, practices, and laws that preclude the installation of water supply wells at this site are:

- City water is available at Seahorse Drive.

- The Waukegan zoning code prohibits wells in new residential developments where city water is available.

- Waukegan restricts the installation of industrial wells.

- The Health Department issues state-required well installation permits and denies permits for locations with known groundwater contamination.

- The county also prohibits installation of wells within a certain distance of contaminated areas.

- Illinois allows "negative easements" to be purchased from adjacent property owners in order to restrict groundwater use.

Monitored Natural Attenuation

Monitored natural attenuation is the natural degradation of contaminants including bioremediation, mixing, dilution, adsorption and other natural processes that reduce the concentration of contaminants over time.

Groundwater Extraction

Groundwater extraction must be combined with treatment and discharge/disposal alternatives to comply with applicable regulations.

Extraction Wells

Extraction wells are used to establish a capture zone for the contaminated groundwater plume. The well location(s) and pumping rates are determined from hydrogeologic models or pumping tests.

French Drain or Horizontal Wells

Groundwater interception is typically achieved using trenches, french drains, and/or horizontal wells. These systems can capture the lateral migration of groundwater contaminants, and may be designed to intercept specific vertical zones.

Groundwater Migration Control/Containment

Groundwater migration control/containment at the Waukegan site could be used to reduce groundwater migration to the lake or harbor.

Hydrodynamic Containment

Hydrodynamic containment consists of a series of extraction wells that form a hydraulic barrier or mound to redirect groundwater flow to a collection device. Hydrodynamic containment is typically used in conjunction with other extraction and treatment technologies to comply with disposal or discharge regulations.

Extraction Wells

Extraction wells establish a capture zone for the contaminated groundwater plume. The well location(s) and pumping rates are determined from hydrogeologic models or pumping tests.

Interception Drains/Horizontal Wells

Groundwater interception is typically achieved using trenches, french drains, and/or horizontal wells. These systems can capture the lateral migration of groundwater contaminants, and may be designed to intercept specific vertical zones of groundwater.

Vertical Barrier

These systems consist of a continuous, impermeable or low permeability barrier, which inhibits the horizontal migration of water, contaminants or vapors. These barriers are generally anchored into a geologic formation of low permeability.

Slurry Wall

Slurry walls consist of a vertical trench backfilled with a bentonite or cement-bentonite slurry as the trench is excavated. Cement-bentonite slurry walls are usually constructed using a slurry of portland cement, bentonite, and water that sets up in the trench forming a solid barrier.

A SoilSaw is a relatively new technology that forms a "mixed-in-place" slurry wall using a continuous wall-forming process. In the SoilSaw barrier system, an innovative jetting beam is used to cut through the soil and inject cement/bentonite grout into the resulting narrow trench. The grout is blended with the soil in situ and hardens to form a highly impermeable barrier wall.

Sheet Pile Wall

Sheet piles can be driven or vibrated into place, provided no significant obstacles such as boulders and debris are likely to be encountered.

Cap

A horizontal barrier or cap placed over contaminated soils minimizes infiltration of precipitation through the affected area, thus reducing the transport of contaminants to groundwater. The caps considered effective at the WCP site include a soil cover, asphalt cap, low permeability cap, and phytoremediation cap.

Soil Cover

A layer of soil and vegetation which covers the contaminated area, encouraging runoff by providing a sloped surface and enhancing evapotranspiration to reduce the net infiltration.

Asphalt Cap

Asphalt or bituminous asphaltic concrete caps are created by grading the site, installing suitable subbase if existing soils are not appropriate from an engineering standpoint, and laying a continuous layer of asphalt paving material over the soil. Stormwater collection is generally required in conjunction with placement of large areas of asphalt.

Low-Permeability Cap

Low-permeability caps employ the use of clay or synthetic membrane to reduce water infiltration and exposure. Clay caps are installed by: (1) grading the site, (2) applying a compacted clay layer over the contaminated area, (3) covering the clay with topsoil, and (4) establishing vegetation to prevent excessive moisture loss and reduce erosion. Drainage layers may be installed above or below the cap. Similarly, synthetic membranes are installed by: (1) subbase grading, (2) placement of a clean fill layer, (3) membrane placement, (4) drainage layer placement, and (5) placement of a topsoil layer to protect the membrane and sustain vegetative growth.

Phytoremediation

A phytoremediation cap consists of developing a community of selected trees, shrubs, and native grasses over the area of concern. The plants restrict the offsite movement of water-soluble contaminants by (1) reducing net infiltration by water removal through plant transpiration, and (2) plant uptake and metabolism of contaminants in soil and groundwater.

Ex-Situ Treatment

Contaminated groundwater can be treated on site using biological, physical, or chemical processes, or can be transported off-site to a private treatment facility for processing. Treatment would be combined with extraction and either discharge or recirculation remedial technologies.

Biological Treatment

Biological treatment of water, like soil biotreatment, detoxifies waste stream organic matter through microbial degradation.

Aerobic

The most common type of biological treatment is aerobic. A number of biological processes can treat water from coal tar sites. These include: (1) conventional activated sludge techniques; (2) various modifications of activated sludge techniques (e.g., those using pure-oxygen activated sludge, extended aeration, and contact stabilization); or (3) fixed-film systems (e.g., rotating biological discs and trickling filters). The activated sludge process introduces aqueous waste into a reactor containing suspension of aerobic bacterial culture. The bacteria culture transforms organics into cell constituents, other organics, carbon dioxide, and water. It also produces new bacterial cells. In the pure-oxygen activated sludge process, oxygen or oxygen-enriched air replaces ambient air and increases the

transfer of oxygen. Fixed-film systems require contact of the aqueous waste stream with microorganisms attached to some inert medium, such as rock or specially designed plastic material (U.S. EPA, 1992a).

Anaerobic

The two most common anaerobic suspended growth processes used for the treatment of wastewater are (1) the anaerobic digestion process and (2) the anaerobic contact process. Anaerobic digestion involves the decomposition of organic and inorganic matter in the absence of oxygen. The major applications are stabilizing concentrated sludges produced from the treatment of wastewater and in the treatment of some industrial wastes. Dilute organic wastes can be treated anaerobically. The anaerobic contact process includes attached growth treatment process using a filter process (Metcalf & Eddy, 1979).

Physical/Chemical Treatment

Physical and chemical treatment processes include precipitation, ion exchange, air or steam stripping, chemical oxidation, membrane filtration, carbon absorption, and sedimentation/filtration.

Precipitation

This process transforms dissolved contaminant into an insoluble solid, facilitating their subsequent removal from the liquid phase by sedimentation or filtration. The process usually employs adjustments of pH, addition of a chemical precipitant, and flocculation. Metals generally precipitate from the solution as hydroxides, sulfides, or carbonates. The solubilities of the specific metal contaminants and the required cleanup standards will dictate the process to be employed (U.S. EPA, 1992b).

Ion Exchange

This process uses reactive ions, contained in a resin or other insoluble exchange material to treat targeted soluble contaminants. The exchange material is either stirred into the water or the water is passed through a bed or column containing the resin. The process can treat a variety of reactants. The water to be treated must first be filtered to avoid premature clogging of the system.

Air Stripping

Air stripping is a mass transfer process that enhances the volatilization of compounds from water by passing air through water to improve the transfer between the air and water

phases. Air stripping is one of the most commonly used processes for remediating ground water contaminated with volatile organic compounds. Air stripping can be performed by using packed towers, tray towers, spray systems, diffused aeration, or mechanical aeration.

Steam Stripping

Steam stripping removes volatile, and sometimes semivolatile, compounds from groundwater or wastewater. This process is capable of reducing volatile organic compounds in water to low concentrations. Steam rather than air is used as the stripping gas.

Chemical Oxidation

This process oxidizes ions or compounds to render them nonhazardous or to make them more amenable to subsequent removal or destruction processes. It is more useful as a polishing step for dilute, relatively clean, aqueous wastes. The cost of chemicals, particularly for nonselective oxidation, limits the application of this technology to heavily contaminated wastes (U.S. EPA, 1992b).

Chemical oxidation primarily treats and/or destroys PCP, nonhalogenated aromatics, PAHs, other polar organic compounds, and nonvolatile and volatile metals found at wood preserving sites. Chemical UV oxidation is a well-established disinfection technology for drinking water and wastewater. Enhanced systems now frequently treat hazardous streams (U.S. EPA, 1992b).

Membrane Filtration

Membrane filtration technologies, such as reverse osmosis and ultrafiltration, separate chemical constituents from water. Reverse osmosis is a pressure-driven, membrane-separation process. It does not destroy the chemicals; it merely concentrates them, making reclamation possible. Reverse osmosis is a low-energy process. It requires no phase change for separation of the dissolved materials, nor latent heat of vaporization, fusion, or sublimation. However, reserve osmosis and ultrafiltration are very sensitive to the presence of fines that can clog the membranes. The membranes are also fragile; they often rupture from overpressure. Reverse osmosis and ultrafiltration can treat groundwater contaminated with PCP, heterocyclics, simple nonhalogenated aromatics, PAHs, other polar organic compounds, some nonvolatile metals, and some volatile metals (U.S. EPA, 1992b).

Carbon Adsorption

In adsorption, one substance binds to the surface of another by physical and/or chemical means. In the adsorption process, contaminants transfer to the adsorbent, the most common of which are activated carbon and resins. The imbalance of forces in the pore walls of the adsorbent allow the contaminants to attach and concentrate. Once adsorption has occurred, the molecular forces in the pore walls stabilize. For further adsorption, regeneration of the adsorbent is necessary. Adsorption can effectively separate various contaminants from aqueous streams (U.S. EPA, 1992b).

Adsorption, especially granular activated carbon (GAC) treatment, has removed PAHs, other polar organic compounds, PCP, non-halogenated aromatics, and some nonvolatile metals from water at wood preserving sites (U.S. EPA, 1992b).

Sedimentation/Filtration

Sedimentation uses gravitational settling to separate suspended particles that are heavier than water. Filtration isolates solid particles by running a fluid stream through a porous medium. The driving force in filtration is either gravity or a pressure differential across the filtration medium. Filtration techniques include separation by centrifugal force, vacuum, or high pressure. Therefore, filtration can separate various contaminant particulates from an aqueous stream (U.S. EPA, 1992b).

Off-Site Treatment

Extracted groundwater can be transported to a privately owned treatment plant. No pretreatment would be required, but may reduce the cost if implemented.

In-Situ Treatment

In-situ treatment technology consists of injecting additives into the aquifer to destroy contaminants. Destruction of the contaminants may be achieved biologically, chemically, or physically. Process options include phytoremediation, biosparging, stripping, chemical fixation, chemical reaction, and electrokinetic remediation.

Biological Treatment

In-situ biological treatment uses microorganisms in the presence of oxygen to degrade groundwater contaminants. Biological treatment is most effective for groundwater in sandy soils Removal efficiencies of 90 to 95 percent (for aromatic hydrocarbons) are possible. Many

factors influence the effectiveness of in-situ biotreatment, including treatment duration, soil type, pH, temperature, and indigenous microorganisms. A typical biotreatment system consists of a series of injection wells that are placed upgradient of the contamination plume. Acclimated microorganisms (if necessary), oxygen, and nutrients are added to the groundwater. Treatability studies are recommended prior to implementation of this technology.

Phytoremediation

Phytoremediation consists of developing a community of selected trees, shrubs, and native grasses. The plants restrict the off-site movement of water soluble contaminants by (1) reducing net infiltration by water removal through plant transpiration, and (2) plant uptake and metabolism of contaminants in soil and groundwater.

Biosparging

Biosparging consists of injecting air into the saturated zone below the groundwater to enhance bioremediation. Biosparging is conducted using a horizontal air sparge system installed at the perimeter of the site, in treatment cells or in the core area.

Stripping

Stripping uses a system of injection wells to introduce air or steam into groundwater where volatiles are removed by air stripping.

Physical/Chemical Treatment

In-situ physical/chemical treatment includes chemical fixation, chemical reaction, and electrokinetic remediation.

Chemical Fixation

Chemical fixation is a system of injection galleries or wells used for chemical complexation and precipitation of metals and inorganics.

Chemical Reaction

Chemical reaction is a system of injection galleries or wells to inject oxidizers such as ozone or hydrogen peroxide into the groundwater.

Electrokinetic Remediation

Electrokinetic remediation uses a series of electrodes placed in soil and groundwater to remove and recover ionic contaminants. The electrodes are placed in porous (or permeable)

casings which are supplied with circulating electrolytes, anolyte for the anodes and catholyte for the cathodes. Ionic contamination is captured in these electrolytes and pumped to the surface, where it is passed through electrochemical ion exchangers. These ion exchanges recover the contaminants selectively, permitting the contaminants to be recovered in reusable form. Treatment can be delivered in situ, by using small scale batch units, or by using large scale multi-batch lagoons (SRI International, 1997).

Discharge

This technology could be implemented if contaminant concentrations in the groundwater or treated groundwater were below applicable discharge standards for discharge to surface water or for recirculation into the groundwater.

Discharge to Surface Water (Lake Michigan/Waukegan Harbor)

Discharge of groundwater to surface water including Lake Michigan and Waukegan Harbor would require treatment.

POTW

The public owned treatment works (POTW) for the Waukegan site is the North Shore Sanitary District wastewater treatment plant. Pretreatment would be required prior to discharge.

Reinjection/Reinfiltration

Reinjection typically consists of using large-diameter wells to: (1) reinject treated water, (2) create a barrier to groundwater flow and contaminant migration, and/or (3) improve the efficiency of a contaminant recovery system (see Hydrodynamic Contaminant above). Reinfiltration uses drain fields or infiltration ponds designed to infiltrate water into the vadose zone or beneath the groundwater surface.

Appendix 4-D

Summary of Technology Evaluation Testing

Appendix 4-D

Summary of Technology Evaluation Testing Results

1.0 Introduction

The following potential remedial technologies were evaluated through a series of technology tests for vadose soil and groundwater from the WCP site:

Vadose-Zone Soil
- Thermal desorption
- Soil washing
- Fuel blending/cement kiln incineration
- Phytoremediation

Groundwater
- Pump test
- Slurry wall backfill mix design
- Electrochemical precipitation
- Aerobic bioremediation

Section 4.6.2 of the RI Report discusses the technology evaluation sampling (Barr, 1995a). The following sections summarize the evaluation results:

2.0 Vadose Zone Soil

2.1 Thermal Desorption

Westinghouse Remediation Services, Inc. (Westinghouse) conducted the evaluation testing for the thermal desorption technology. On November 5, 1993 a work plan was prepared for the study titled *Work Plan for Technology Evaluation Testing of Thermal Desorption for the Waukegan Manufactured Gas and Coke Plant Site*. The testing was conducted from December 1993 until January 1994. The results of the testing are included in the report titled *Technology Evaluation Testing of Thermal Desorption for the Waukegan Manufactured Gas and Coke Plant Site* dated July 27, 1995. These reports have been submitted to the U.S. EPA.

The media from the site used in the testing included a vadose zone soil sample and a pond sediment sample. The vadose zone soil sample was collected from Test Trench 24, was composed mostly of oily sand and slag, and would be considered PAH Remediation Zone soil. This sample was tested using both the thermal desorption and soil washing technology discussed below. The pond sediment was collected from Test Trench 30.

The thermal desorption process consists of the following steps:

1. Contaminated soil is fed into a sealed primary heating chamber that operates slightly below atmospheric pressure in a oxygen-deficient, non-combustible environment.

2. Heating rods heat the soil via infrared thermal radiation to temperatures above the boiling points of the contaminants, causing them to desorb from the soil and volatilize into the gas stream.

3. Volatilized contaminants are transferred to the off-gas treatment system consisting of a quench/scrubber unit that condenses the contaminants. Off-gases are treated with a chevron mist eliminator and vapor carbon filter.

4. Condensed contaminants and water are treated in a water treatment system consisting of an oil/water separator and an air-water cooler/heat exchanger.

The key conclusions from the thermal desorption testing were:

• Thermal desorption of PAH Remediation Zone soil is feasible. Test results indicated effective treatment would require a temperature of 1,000°F and a detention time of 20 minutes. Because of the high temperature and long detention time this technology may not be cost effective for PAH Remediation Zone soil.

• Benzene was not entirely volatilized during the thermal desorption testing. Since volatile organic compounds such as benzene volatilize more readily than semivolatile organic compounds, the incomplete removal of benzene may not accurately reflect the performance of this technology.

• Thermal desorption is feasible for reducing the PAH concentration of the pond sediment. However, the pond sediment ignited after testing when exposed to air. Westinghouse claims that their full-scale thermal desorption equipment is designed to avoid this problem.

In more recent work, thermal desorption technology has been successfully applied to the remediation of manufactured gas plant soils. The *Field Demonstration of Thermal Desorption of Manufactured Gas Plant Soils*, prepared for the Electric Power Research Institute (EPRI) documented that the technology achieved removal/destruction percentages of 89 percent to 99.7 percent for PAH compounds in moist, clay-rich soils. The concentrations of total PAHs for the influent samples ranged from 84 mg/kg to 3,733 mg/kg. The concentrations of carcinogenic PAHs of the influent samples ranged from 17 mg/kg to 376 mg/kg. The range of removal/destruction for carcinogenic PAHs was from 79 percent to greater than 99 percent. The excavation cleanup goal for the field demonstration site was 100 mg/kg carcinogenic PAHs and 500 mg/kg total PAHs, which was achieved. Two other MGP sites located in California were also included in the study, and also completed successful thermal desorption treatment of PAH compounds.

Although thermal desorption technology has been demonstrated to cost-effectively remediate full-scale MGP sites, several problems were observed during testing of Waukegan soil. The successful application of this technology may require blending the soil to create a more homogeneous mix than the PAH Remediation Zone or pond sediment used in the test. This blending process may not be cost effective.

Other thermal treatment technologies may be more suitable for the Waukegan soils. For example, in-situ thermal desorption using a "thermal blanket" system is a promising new technology for vadose zone organic contamination. The system uses an insulated thermal blanket with heaters operated at a negative pressure to collect contaminants, reduce upward heat losses, and prevent contaminant migration and eliminate odors. Off-gas emissions are controlled by a vapor extraction system. This system has been demonstrated as a full scale operation at other sites to successfully remove organics from Vadose Zone soil.

2.2 Soil Washing

Westinghouse conducted evaluation testing for the soil washing technology. On November 29, 1993 a work plan was prepared for the study titled *Work Plan for Technology Evaluation Testing of Soil Washing Desorption for the Waukegan Manufactured Gas and Coke Plant Site*. The testing was conducted from March 1994 until April 1994. The results of the testing are included in the report titled *Technology Evaluation Testing of Soil Washing for the Waukegan Manufactured Gas and Coke Plant Site* dated July 27, 1995. These reports have been submitted to the U.S. EPA.

The media from the site used in the testing was from the same vadose zone soil sample used for the thermal desorption testing. The Westinghouse soil washing process consists of three general treatment steps:

1. Particles greater than 6 inches in diameter are mechanically separated from the treatment material during the initial screening wash step.

2. Contaminants are separated from sand and silt-sized particles during the solids break up/wash step. The remaining contaminant is suspended in the liquid or attached to the fines.

3. Based on density and size, solids (washed sands and silts) are separated during the leaching/washing step. Contaminants concentrated in fines and aqueous solution are then removed.

The key conclusion from the soil washing technology test was:

• Soil washing process did not separate or remove the PAHs from the large-size fraction of the soil.

2.3 Fuel Blending/Cement Kiln Incineration/Co-Burning

Treatment of tar-saturated soil at a cement kiln involves using the tar waste as a supplemental fuel in the production of cement. The tar material would be excavated from the site and either used in its semi-solid state or transformed into a pumpable form and burned as a fuel at an offsite location

Five waste service vendors offering fuel blending/cement kiln incineration were contacted and asked to characterize the WCP tar waste relative to their acceptance criteria. In October 1993, five 1-gallon buckets of tar-saturated soil were shipped to the following vendors: Cadence Environmental Energy (Michigan City, Indiana), Heritage Remediation (Indianapolis, Indiana), 7-7, Inc. (Wooster, Ohio), Southdown Environmental (Crestview Hill, Kentucky) and Nortru, Inc. (Detroit, Michigan). Four of the vendors, excluding Nortru, indicated that the tar samples submitted for analysis met the acceptance criteria and would be suitable as a supplementary fuel source at a cement kiln.

Co-burning of PAH-contaminated soil in an electric generating station is a similar technology to fuel blending and cement kiln incineration. This technology has been used successfully at numerous MGP sites and has been approved in concept and in specific applications by U.S. EPA. Several power plants have been permitted to accept MGP wastes for co-burning. For the WCP site, PAH Remediation Zone soil could be excavated, processed, transported, and co-burned at Illinois Power's Baldwin Station located near St. Louis, Missouri. Other facilities may become available in the future. The soil would require some processing to remove large debris (over 1-foot size) and would require mixing with a non-cohesive material to improve materials-handling properties and to reliably pass TCLP. Wood ash or coal may be viable non-cohesive materials to use for mixing.

2.4 Phytoremediation

Dr. John Fletcher of the University of Oklahoma completed the phytoremediation technology evaluation. The evaluation was based on a January 28, 1998 visit to the WCP site and the Illinois Beach State Park located four miles north of the site. The results previously submitted to U.S. EPA in the report titled *Implementation of Phytoremediation at the Waukegan, Illinois, Gas and Coke Plant Site* (Fletcher, 1998).

The evaluation concluded that plants and associated microorganisms introduced at the Waukegan site would accomplish three different primary objectives:

1. Prevent soil erosion to minimize the contaminant migration via wind and surface water

2. Restrict contaminant leaching from soil to groundwater through evapotranspiration

3. Promote degradation of PAHs and other organic contaminants by enhancing soil aeration and providing microbial substrates for contaminant degradation.

The key conclusions of the phytoremediation technology evaluation were:

- Phytoremediation is feasible technology at the WCP site. The climate, terrain, and soil conditions are appropriate for successful implementation.

- Based on site conditions, including climate, contaminant concentrations, and remediation goals, specific plants were selected to maximize the degradation of organic pollutants. Tall

grass species selected as appropriate ground cover included little bluestem, big bluestem, indiangrass, and switch grass. Mulberry trees were selected for areas with high and/or deep PAH contamination.

- Site preparation activities, such as plowing/harrowing and positioning the most highly impacted soil near the ground surface, should be performed prior to planting. Plowing will enable plant roots to grow and penetrate lower zones. Oxygen-dependent microbial degradation and plant uptake are most active near the surface, where the most highly impacted soil would be placed.

- Once the grasses and trees are established, they will stimulate microbial growth by enhancing soil aeration and providing microbial substrates for PAH degradation. The gradual degradation of pollutants will occur continuously; after a 15 or 20 year period, insignificant amounts of PAHs will remain.

3.0 Groundwater

3.1 Pump Test

On November 4, 1993, Barr Engineering Company performed a constant-rate pumping test on the sand aquifer to determine its hydraulic properties. The pumping test results were previously submitted to U.S. EPA in the *Remedial Investigation Report* (Barr, 1995).

The pumping test results yielded the following information:

1. A pumping rate of 25 gpm was maintained with 5 percent of this target rate for a period of 9 hours.

2. The mean transmissivity computed from the pumping test was 0.84 ft^2/min (1,200 ft^2/day), yielding a hydraulic conductivity value of 47 ft/day (1.7 x 10^{-2} cm/sec). This information, along with other measures of hydraulic conductivity, are the basis for the site-wide hydraulic conductivity estimate of 31 feet/day (1.1 x 10^{-2} cm/sec). These values fall within the expected range for silty sand aquifers (0.4 ft/day to 400 ft/day; Freeze and Cherry, 1979).

3. The mean ratio of vertical to horizontal hydraulic conductivity is estimated to be 0.24.

The key conclusion from the pumping test was:

- The hydraulic properties of the sand aquifer indicate it is capable of sustaining groundwater pumping.

3.2 Slurry Wall Backfill Mix Design

IT Corporation conducted the slurry wall backfill mix design testing. A work plan was prepared in November 1994 for the study and titled *Slurry Wall Backfill Mix Design Work Plan*. The testing was conducted from March 1995 until October 1995. The results of the testing are included in the report titled *Slurry Wall Backfill Mix Design, Waukegan Manufactured Gas and Coke Plant Site, Waukegan, Illinois* dated November 1995. These reports have been submitted to the U.S. EPA.

The potentially representative slurry wall materials evaluated for this technology were offsite clay, onsite sand, offsite sand, and onsite fill. Three borrow sources were identified and evaluated to determine a clay source for the backfill mix design because clay is not available onsite. Onsite sand was collected from soil boring SB-57 from a depth of 7 to 24 feet and used in the backfill mix design. Onsite fill material was collected near the location of MW-7D and was visually observed to determine whether this material could be used in the backfill mix. An alternate offsite sand source was also evaluated should the onsite sand contain deleterious or contaminated materials along the slurry wall alignment.

The representative waters evaluated for this technology were offsite noncontaminated water and onsite contaminated water. The noncontaminated water was collected from the local water treatment plant and was used in the backfill mix designs. The onsite contaminated water was collected from monitoring well MW-9D and was used for bentonite filter cake and long-term backfill mix permeability testing.

The key conclusions from the slurry wall backfill mix design testing were:

- The slurry wall backfill mix design is feasible. The backfill mix consisting of 40 percent clay, and 60 percent onsite sand with 1.0 percent bentonite met both the short- and long-term permeability testing requirements. The long-term permeability requirement of 10^{-7} cm/sec or less was achieved under the conditions tested.

- Onsite contaminated groundwater may be used; its chemical characteristics had a negligible effect on permeability testing.

3.3 Electrochemical Precipitation

Barr Engineering Company performed an electrochemical precipitation pilot study in October 1993 during the Phase II remedial investigation. The procedures and results were presented in the *Remedial Investigation Report* (Barr, 1995). Onsite groundwater from pumping well PW-1, along with water from well development and purging, was processed through an Andco water treatment system. This system consisted of electrochemical precipitation to remove arsenic and GAC to remove organic compounds.

Treatability results indicated that 95 to 99 percent of the arsenic was removed with the electrochemical precipitation system under operational conditions. Influent concentrations of arsenic III ranged from less than the detection limit of 0.01 to 0.113 mg/L and arsenic V ranged from 0.378 to 1.09 mg/L. Final concentrations of arsenic III ranged from less than the detection limit of 0.01 to 0.013 mg/L and arsenic V ranged from less than the detection limit of 0.01 to 0.064 mg/L. The pattern of removal performance was the same for arsenic III as for arsenic V. The total removal for arsenic V was greater than arsenic III. One test designed to explore the envelope of useful operating conditions only achieved 63 percent removal. In that test, the initial pH had been adjusted to 6. The operational conditions determined by the pilot test included a 137 ppm iron dosage for a flow rate of 10 gpm, with no pH adjustment required.

The electrochemical precipitation system generated a precipitate which was subsequently dewatered with a filter press to produce a filter cake. A sample of the filter cake was analyzed for TCLP for volatile and semivolatile organic compounds, pesticides and RCRA metals to evaluate disposal alternatives. The filter cake sample did not exceed the TCLP thresholds for hazardous waste classification.

The key conclusions from the pilot study were:

- Electrochemical precipitation is feasible and is an effective technology for the removal of arsenic in site groundwater.

- The filter cake produced during the process may potentially be disposed of as non-hazardous waste.

- Several factors must be considered if this technology is applied full-scale at the site. Operating the treatment system was fairly labor-intensive, and the equipment was prone

to breakdowns. Electrochemical precipitation would need to be combined with treatment processes to address contaminants other than arsenic (i.e., phenols and ammonia).

3.4 Aerobic Bioremediation of Site Groundwater

Fluor Daniel/Groundwater Technology, Inc. evaluated the feasibility of aerobic bioremediation of site groundwater. Various mixtures of groundwater from impacted and unimpacted areas of the site were analyzed. The treatability testing protocols, results, and data interpretation were presented in the May 1998 *Treatability Study to Evaluate Aerobic Bioremediation of Contaminated Site Groundwater, Waukegan Manufactured Gas and Coke Plant Site.*

The study yielded the following information:

(1)   Undiluted core area groundwater did not support any biological activity.

(2)   Phenols were successfully degraded in all dilutions consisting of 33 percent or less core area groundwater.

(3)   Phenols and thiocyanate were successfully degraded with an inoculum consisting of site soil in a dilution consisting of 10 percent core area groundwater and 90 percent unimpacted site groundwater.

(4)   Ammonia was degraded biologically in dilutions consisting of up to 10 percent core area groundwater. After re-inoculation of the test water with additional nitrifying organisms ammonia was successfully degraded biologically in dilutions consisting of as much as 33 percent core area groundwater.

(5)   Ammonia degradation was inhibited or stopped completely as long as both phenol and thiocyanate were present in the water for both site water mixes and synthetic control mixes.

(6)   For site water mixes, after phenol and thiocyanate degradation was complete, ammonia degradation was either slower than in synthetic control mixes, or non-existent. This suggests that the site water contains an unidentified compound or group of compounds inhibitory to ammonia degradation. It also appears that an acclimation period is

necessary to allow a significant population of nitrifying organisms to grow and then degrade the ammonia in site water mixes.

The key conclusions of the aerobic bioremediation study were:

- Aerobic biodegradation is a feasible technology for the effective removal of phenol and thiocyanate from WCP site groundwater.

- The effectiveness of the treatment relies significantly on the dilution of impacted groundwater, and reliable ammonia degradation may be challenging to induce artificially at the site. Therefore, the successful implementation of aerobic bioremediation may be difficult, and the overall effectiveness of the system may be less than optimal.

Appendix 4-E

Letters Discussing Implementation
of Land Disposal Restrictions at MGP Sites

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M E M O R A N D U M

TO: USWAG Policy Committee   **PRIVILEGED &**

USWAG Remediation Waste Committee

USWAG Low Volume Waste Committee   **CONFIDENTIAL**

EEI Manufactured Gas Plant Subcommittee & Task Force

FROM: William R. Weissman   *[signature]*

RE: EPA Issues Interpretive Letter to Facilitate Compliance with the Phase IV
RCRA Land Ban Requirements at MGP Remediation Sites

DATE: August 24, 1998

Late on Friday, August 21, EPA informed us that it was issuing an interpretive
letter to provide guidance to manufactured gas plant ("MGP") site managers on
compliance with the new Phase IV land ban restrictions ("LDR") applicable to MGP
remediation wastes and contaminated soils. As you know, the Phase IV rule extended
the LDRs to MGP wastes and soils that exhibit a hazardous characteristic when
generated. *See* 63 Fed. Reg. 28556, 28574-75 (May 26, 1998). The EPA interpretive
guidance responded to a USWAG letter to EPA dated May 11, 1998, that described a
range of MGP remediation scenarios. Two days later, a team of utility representatives
met with EPA staff to stress the importance of a flexible interpretation of the LDR rules
to avoid disrupting MGP remediations. EPA's detailed guidance letter is attached. [1]

EPA's letter appears to meet our goal of a flexible interpretation of the LDR
requirements to minimize disruption to MGP site remediation strategies. Although
most portions of the letter refer to contaminated soils, the analysis applies equally to

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[1]   The copy of the letter we received by fax on Friday contains a typographical error that
EPA plans to correct in the copy of the letter that will be mailed to us today. The mailed
copy will also contain several attachments. We will transmit the corrected letter and
attachments when we receive them to replace today's temporary version

wastes subject to LDRs except that soils qualify for the less stringent alternative soils treatment standards adopted in the Phase IV rule. [2] The critical assumption in the EPA analysis is that companies remediating MGP sites will decharacterize any MGP waste or soils that otherwise would require compliance with the RCRA hazardous waste permit program. [3] The major points in EPA's letter are:

- Consolidating MGP waste or soils may take place in an "area of contamination" ("AOC") prior to generating the waste (i.e., before it is removed from the land). If, after consolidation, the waste or contaminated soil does not exhibit a hazardous characteristic, the waste or soil has no further regulatory obligations under the RCRA Subtitle C permit program. On the other hand, if the consolidated waste or soil exhibits a characteristic, decharacterization may take place after generation at the remediation site in a 90-day accumulation unit (i.e., tank, container, or containment building).

- If decharacterization occurs after generation, LDR requirements attach to the waste or the soil and applicable LDR treatment standards (i.e., universal treatment standards ("UTS") for waste; 90% constituent concentration reduction capped at 10 times UTS for soils) must be met prior to land disposal. The LDR storage prohibition also applies to this waste until the applicable treatment standards are met and the reporting and recordkeeping requirements of 40 C.F.R. § 268.9 must be satisfied.

- An exception to the foregoing point occurs when MGP waste or soils are going to a coal-fired utility boiler (i.e., a Bevill device), in which case the ash would not be subject to LDRs prior to land disposal because the ash is a Bevill waste exempt from LDRs and the decharacterized waste or soils would not be regarded as a "prohibited waste" under the LDR program. However, there is a one-time notice requirement that must be satisfied. See 40 C.F.R. § 268.7(a)(7).

- Where LDRs have attached to decharacterized MGP waste, intermediate management activities prior to ultimate treatment may raise issues of prohibited

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[2] It is generally to a company's advantage if the excavated remediation waste meets the definition of soil. See 40 C.F.R. § 268.2(k); 63 Fed. Reg. at 28620. However, mixing of hazardous remediation waste with soil to reclassify the waste into soil is prohibited. Id. at 28621.

[3] If the waste is not decharacterized, it is subject both to LDRs as well as all other Subtitle C requirements. On the other hand, if the waste did not exhibit a hazardous characteristic when generated, neither the LDRs nor any other aspect of Subtitle C applies to the waste. See id. at 28617-18.

land disposal. EPA concludes that under current rules, management in tanks, containers or containment buildings does not constitute land disposal. Since the decharacterized waste is not a hazardous waste, these units need not comply with hazardous waste permit or management standards.

- If such management activities for decharacterized waste take place in units that are not tanks, containers or containment buildings, the regulatory agency overseeing the remediation should make a site-specific determination whether the placement of decharacterized MGP waste or soil constitutes land disposal. To make that determination, EPA Regions or State agencies (1) must consider the mandatory definition of land disposal in RCRA § 3004(k), (2) should consider the relevant requirements for tanks, containers and containment buildings, and (3) if these requirements are modified, should determine whether the unit will prevent or control unacceptable releases of decharacterized soil and hazardous constituents to the environment. This is not a zero release standard, but a grant of discretionary authority to the overseeing regulatory agency to determine in the context of its approval of the site remediation what constitutes "unacceptable releases" and the adequacy of the management unit in "controlling" releases.

The EPA letter also provides some valuable guidance on the scope of the dilution prohibition in 40 C.F.R. § 268.3. While dilution is generally prohibited "as a substitute for adequate treatment" to meet an LDR treatment standard, dilution for other purposes is not necessarily prohibited. For example:

- Mixing of MGP waste or soil with coal or other combustibles that renders it nonhazardous prior to burning in a utility boiler is not impermissible dilution because this mixing produces a physical change to the waste stream that enhances its combustibility and thereby facilitates proper treatment.

- Mixing or other pre-treatment of MGP waste or soil necessary to facilitate proper treatment (e.g., to prevent thermal desorption units from operating at excessively high temperatures) is permissible.

- Mixing of MGP waste or soil that merely increases the volume of the waste to lower constituent concentrations or releases excessive amounts of hazardous constituents to air is impermissible dilution.

In sum. EPA's message on how to minimize the disruption of MGP remediations is clear:

- Use best efforts to ensure that any MGP waste or soils do not exhibit a hazardous characteristic when generated (i.e., removed from the land). This can be achieved by consolidating wastes of varying constituent concentrations within the AOC.

- If decharacterization cannot be accomplished in the AOC, decharacterize any hazardous waste on-site in a 90-day accumulation unit using materials that will produce a chemical or physical change in the waste or will otherwise facilitate the ultimate treatment or make the waste more amenable to the particular treatment technology. While LDRs may attach to this waste (unless it is destined for co-burning in a Bevill device), decharacterization will effectively remove any further Subtitle C regulatory obligations.

- If the waste has been decharacterized but remains subject to LDR requirements, intermediate management steps prior to compliance with applicable LDR treatment standards may not involve "land disposal" as defined by RCRA § 3004(k), meaning that the management unit should be a tank, container, containment building, or some other unit that the overseeing regulatory agency is satisfied "will prevent or control unacceptable releases of decharacterized contaminated soil and hazardous constituents to the environment."

If you have any questions or comments on the EPA letter, please call Bill Weissman (202-861-3878) (E-Mail: wweissman@pipermar.com). Please keep in mind that today is the effective date of the LDRs for MGP wastes.

Attachment

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

WASHINGTON, D.C. 20460

AUG 2 1 1998

William R. Weissman
Piper & Marbury L.L.P.
1200 Nineteenth Street, N.W.
Washington, D.C. 20036-2430

OFFICE OF
SOLID WASTE AND EMERGENCY
RESPONSE

Dear Mr. Weissman:

Thank you for your letter of May 11, 1998 and for meeting with us to discuss the Utility Solid Waste Activities Group's (USWAG's), Edison Electric Institute's (EEI's) and the American Gas Association's (AGA's) concerns regarding the effects the land disposal restrictions (LDR) treatment standards published on May 26, 1998 may have on cleanup of manufactured gas plant sites. Like you, we are interested in encouraging and facilitating cleanup of manufactured gas plant sites in a way that is both efficient, economical and protective of human health and the environment. Before addressing the specific concerns raised in your letter, we will review some of the general principles that govern application of RCRA to contaminated soil.

As you know, contaminated soil, of itself, is not hazardous waste and, generally, is not subject to regulation under RCRA. Contaminated soil can become subject to regulation under RCRA if the soil "contains" hazardous waste. EPA generally considers contaminated soil to contain hazardous waste: (1) when soil exhibits a characteristic of hazardous waste; and, (2) when soil is contaminated with hazardous constituents from listed hazardous waste above certain concentrations. 63 FR at 28617 (May 26, 1998).

If contaminated soil contains hazardous waste, then it is subject to all applicable RCRA requirements until the soil no longer contains hazardous waste (i.e., until the soil is decharacterized or, in the case of soil containing listed hazardous waste, until EPA or an authorized state determines that the soil no longer contains listed hazardous waste). In some circumstances, soil that no longer contains hazardous waste, while generally not subject to RCRA requirements, will remain subject to the land disposal restrictions. See 63 FR at 28618 (May 26, 1998) and other sources cited therein. This may be the case if contaminated soil from manufactured gas plants exhibits a hazardous characteristic when first generated (i.e., when first removed from the land) and is subsequently decharacterized. Note that if contaminated soil from manufactured gas plant sites does not exhibit a characteristic of hazardous waste or contain listed hazardous waste when first generated (i.e., when first removed from the land), then the soil is not subject to any RCRA requirements, including the land disposal restrictions. 63 FR 28618 (May

26. 1998).[1]

We understand that at some manufactured gas plant cleanup sites, soil is consolidated within an area of contamination prior to being removed from the land (i.e., generated). This practice, and the area of contamination policy generally, is not affected by the May 26. 1998 rulemaking. Contaminated soil may be consolidated within an area of contamination before it is removed from the land (i.e., generated); the determination as to whether the soil exhibits a characteristic of hazardous waste or contains listed hazardous waste may be made after such consolidation. The Agency's most recent guidance on the area of contamination policy is enclosed for your information.

We understand from our discussions that your concerns center around management of contaminated soil that exhibited a characteristic of hazardous waste when first generated but has subsequently been decharacterized. We will address two questions in this letter: (1) what are the Agency's rules and policies concerning land disposal of decharacterized wastes, including decharacterized contaminated soil and (2) when decharacterized contaminated soil remains subject to the land disposal restrictions, what requirements apply prior to land disposal.

1.   **What are the Agency's rules and policies concerning land disposal of decharacterized wastes, including decharacterized contaminated soil?**

Decharacterized waste (and decharacterized contaminated soil) is not hazardous waste, and is generally not subject to the Subtitle C regulations. Nonetheless, as you are aware, under certain circumstances decharacterized wastes (and decharacterized contaminated soils) remain subject to LDR treatment requirements. See generally, Chemical Waste Management v. EPA, 976 F. 2d 2, 13-14 (D.C. Cir. 1992).

When decharacterized wastes (and decharacterized contaminated soils) remain subject to LDR treatment requirements (i.e., as explained above, when the soils exhibit a hazardous waste characteristic when removed from the land) they must meet applicable LDR treatment standards prior to land disposal, before they can be land disposed, (i.e., before they can be placed in a land disposal unit). RCRA 3004(k) defines land disposal to include, but not be limited to, any placement in a landfill, surface impoundment, waste pile, injection well, land treatment facility, salt dome formation, salt bed formation, or underground mine or cave. Furthermore, EPA has found, in other contexts, that open pits, flat or low walled concrete pads that do not effectively

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[1] The exception to this general rule is soil contaminated by listed hazardous waste when the listed hazardous waste is land disposed after the effective date of applicable LDR treatment requirements without meeting such applicable requirements. In this case, the contaminated soil would be subject to land disposal restriction treatment requirements regardless of whether it "contained" hazardous waste when first removed from the land unless there is a finding that hazardous constituent levels are sufficiently low so that threats to human health and the environment posed by land disposal of the soil are minimized. See 63 FR at 28618 (May 26, 1998). As we understand the conditions at most manufactured gas plant cleanup sites, we believe this case will seldom be presented during manufactured gas plant cleanups because soil at manufactured gas plant sites is not typically contaminated by listed hazardous waste.

contain hazardous wastes and hazardous constituents may constitute land disposal. See the enclosed letter from Sylvia Lowrance, U.S. EPA to Richard Wasserstrom dated October 29, 1992. However, EPA's longstanding view is that placement in tanks, containers, and containment buildings is not land disposal. See, e.g., 57 FR 37211 (August 18, 1992) (establishing standards for containment buildings). EPA has established design and operating requirements for tanks, containers and containment buildings used to treat and store hazardous waste. Clearly, units used for treatment or storage of decharacterized contaminated soil which meet these requirements would not be considered land disposal units and may be used to treat or store decharacterized contaminated soil without the approval of EPA or an authorized state. However, since decharacterized contaminated soil is no longer subject to regulation as hazardous waste (except, potentially, for land disposal treatment requirements), treatment and storage units used to manage decharacterized contaminated soil are not hazardous waste management units and do not have to be designed or operated in accordance with RCRA Subtitle C hazardous waste regulations or receive hazardous waste permits. If decharacterized contaminated soil will be treated or stored in a unit which is not a tank, container, or containment building, EPA or an authorized state should make a site-specific determination as to whether or not placement of decharacterized contaminated soil in the unit constitutes land disposal. In making such determinations, in addition to the mandatory consideration of the definition of land disposal in section 3004(k), EPA will consider (and recommends that authorized states similarly consider) the relevant requirements established by the Agency for tanks, containers, and containment buildings and, if these requirements are modified, whether the treatment or storage unit will prevent or control unacceptable releases of decharacterized contaminated soil and hazardous constituents to the environment. These determinations should be made in the context of your on-going MGP site cleanups and should be included in the public notices which are typically part of cleanup processes. We recognize that determinations about containment units will likely be made predominantly by authorized states and that due to site- and waste-specific variability containment units will have to accommodate the variety of conditions that may be presented during cleanup of MGP sites.

2. **When decharacterized contaminated soil remains subject to the land disposal restrictions, what requirements apply prior to land disposal ?**

When decharacterized contaminated soil remains subject to the land disposal restrictions, three types of requirements apply. First, the soil must be treated to meet applicable land disposal treatment standards prior to land disposal. Second, as discussed above, prior to land disposal the soil must be treated or stored in an appropriate type of unit (i.e., a unit that is not a land disposal unit). Third, to ensure that applicable land disposal treatment standards are met, certain tracking, paperwork and other requirements must be met.

(a) **Treatment to meet applicable land disposal treatment standards.** As just noted above, like any other material subject to the land disposal restrictions, decharacterized soils from MGP cleanup sites must be treated to meet applicable land disposal restriction treatment standards prior to land disposal. In the case of contaminated soils subject to the land disposal

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restrictions, generators may choose between meeting the universal treatment standard for the contaminating hazardous waste or meeting the alternative soil treatment standards. For decharacterized contaminated soils, meeting the universal treatment standard for the contaminating hazardous waste would require treatment of the formerly characteristic constituent and all underlying hazardous constituents to the universal treatment standards. Meeting the alternative soil treatment standards would require treatment of the formerly characteristic constituent and all underlying hazardous constituents to reduce constituent concentrations by 90 percent or to achieve ten times the universal treatment standard. Note that, as with any other material subject to the land disposal restrictions, contaminated soil may qualify for treatment variances under certain circumstances, see 40 CFR 268.44.

(b) Storage and treatment prior to land disposal. As discussed above, although decharacterized contaminated soil is not hazardous waste and, generally, is therefore not subject to RCRA Subtitle C requirements, because it remains subject to the land disposal restrictions, it must be stored and treated in appropriate units (i.e., units that are not land disposal units) until treatment standards are met.

(c)Tracking, paperwork and other requirements. If decharacterized contaminated soil is stored, the storage prohibition of RCRA 3004(j) generally applies. This means that the decharacterized contaminated soil can only be stored for the purpose of accumulating necessary quantities of hazardous wastes to facilitate proper recovery, treatment, or disposal. See 40 CFR 268.50.

For decharacterized contaminated soil. the reporting and record keeping requirements of 40 CFR 268.9 apply. For example, if characteristic soil from an MGP cleanup is decharacterized at the site where it was generated, then sent off-site for further treatment to achieve LDR standards in a thermal desorption unit, the generator of the contaminated soil must complete a one-time notification and certification. The one-time notification and certification provides a description of the soil as initially generated, including applicable hazardous waste codes, treatability groups, and underlying hazardous constituents. It also provides information about the facility which will receive, and treat, the decharacterized soil. Thus, in this example the generator of the contaminated soil would identify the facility operating the thermal desorption unit. A copy of the one time notification and certification must be placed in the generator's files and sent to the appropriate EPA region or authorized state. These requirements create a tracking system so EPA and authorized states can determine that materials subject to the land disposal restrictions arrive at the right place and are appropriately treated prior to land disposal.

Furthermore, the dilution prohibition of 40 CFR 268.3 applies to the decharacterized contaminated soil until applicable LDR treatment standards are achieved. As you are aware, dilution is normally prohibited as a means of achieving the LDR treatment standards, including for characteristic (and decharacterized) wastes. See Chemical Waste Management v. EPA. 976 F. 2d 2, 15-19 (D.C. Cir. 1992).

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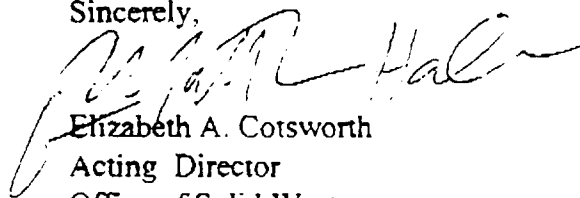
We understand that often decharacterized contaminated soils from MGP cleanup sites are returned to the utility's power plant and mixed with coal or other combustibles prior to burning in a utility boiler. The Agency does not consider this process a form of impermissible dilution. Mixing MGP waste with coal or other combustibles results in a physical change to the waste stream that makes the waste more amenable to combustion (which, in addition to being a type of energy recovery, is a form of treatment that destroys or removes the hazardous constituents), and thus facilitates proper treatment.

In addition to mixing with coal or other combustibles, other types of mixing or treatment of decharacterized contaminated soil may be permissible prior to final treatment, provided that these processes produce chemical or physical changes and do not merely (1) dilute the hazardous constituents into a larger volume of waste so as to lower the constituent concentration or (2) release excessive amounts of hazardous constituents to the air. If mixing or other pre-treatment is necessary to facilitate proper treatment (e.g., destruction or removal, such as burning in a boiler) in meeting the treatment standards then dilution is permissible. See 51 FR 40592 (November 7, 1986) and 53 FR 30911 (August 16, 1988).

Note that, in some instances, burning decharacterized contaminated soil mixed with coal in a utility boiler may implicate the Bevill amendment. As you are aware, EPA's position is that wastes which are covered by the Bevill amendment are not subject to LDR requirements. 40 CFR 268.1(b); see also Horsehead Resource Development Co. v. Browner, 16 F. 3d 1246, 1260-61 (D.C. Cir. 1994) (upholding EPA's position). Consequently, if decharacterized contaminated soil is burned in utility boilers along with coal and the resulting combustion ash is within the scope of the Bevill amendment, LDR standards do not have to be met for that ash, nor would the decharacterized contaminated soils be considered to be a prohibited waste. In this case, the only reporting and recordkeeping requirement required is a one-time notice kept in the facility's records. See 40 CFR 268.7 (a)(7).

We appreciate your patience with the Agency in responding to your concerns. If you need further assistance, please contact Rita Chow of my staff at (703) 308-6158.

Sincerely,

Elizabeth A. Cotsworth
Acting Director
Office of Solid Waste

Enclosure (2)

5

MAR 1 3 1996

MEMORANDUM

SUBJECT: Use of the Area of Contamination (AOC) Concept During RCRA Cleanups

FROM: Michael Shapiro, Director
           Office of Solid Waste

           Stephen D. Luftig, Director
           Office of Emergency and Remedial Response

           Jerry Clifford, Director
           Office of Site Remediation Enforcement

TO: RCRA Branch Chiefs
           CERCLA Regional Managers

This memorandum confirms that, under current regulations, certain broad areas of contamination (AOCs) may be considered RCRA landfills. Under certain conditions, hazardous wastes may be moved within such areas without triggering RCRA land disposal restrictions or minimum technology requirements. This memorandum also describes the distinctions between the final Corrective Action Management Unit (CAMU) regulations and the Area of Contamination (AOC) approach, and encourages appropriate use of both options to expedite remedial actions.

Area of Contamination Approach

The area of contamination concept was discussed in detail in the preamble to the National Contingency Plan (55 FR 8758-8760; March 8, 1990). In this discussion, EPA clarified that certain discrete areas of generally dispersed contamination (called "areas of contamination" or "AOCs") could be equated to a RCRA landfill and that movement of hazardous wastes within those areas would not be considered land disposal and would not trigger the RCRA land disposal restrictions. The NCP also discusses using the concept of "placement" to determine which requirements might apply within an AOC. The concept of "placement" is important because placement of hazardous waste into a landfill or other land based unit is considered land disposal,

which triggers the land disposal restrictions, and may trigger other RCRA requirements including permitting (at a non-CERCLA site), closure and post-closure. In the NCP, EPA stated, "placement does not occur when waste is consolidated within an AOC, when it is treated in situ, or when it is left in place." Placement does occur, and additional RCRA requirements may be triggered, when wastes are moved from one AOC to another (e.g., for consolidation) or when waste is actively managed (e.g., treated *ex situ*) within or outside the AOC and returned to the land. Additional information on when placement does and does not occur is provided in the attached guidance document, *Determining When Land Disposal Restrictions (LDRs) Are Applicable to CERCLA Response Actions*, OSWER Directive 9347.3-05FS, July 1989.

Although the AOC concept was initially discussed in the context of the CERCLA program, it applies equally to RCRA corrective action sites, cleanups under state law, and voluntary cleanups[1]. For additional information on the AOC concept, see, for example, the October 9, 1990 memorandum from Sylvia Lowrance to David Ullrich, "Replacement of Contaminated Soil and Debris Treated under a Treatability Variance," the January 7, 1991 letter from Don Clay to Richard Stoll, and the June 11, 1992 letter from Sylvia Lowrance to Douglas Green (attached).

The interpretations of landfill, placement and the area of contamination concept discussed in the NCP preamble were reiterated by EPA in the 1990 subpart S proposal (55 FR 30798, July 27, 1990). In the 1990 proposal, EPA termed AOCs at RCRA facilities "Corrective Action Management Units" or "CAMUs." Although the name was changed, from AOC to CAMU, the CAMU concept discussed in the 1990 proposal was equivalent to the AOC concept (although, as discussed below, the CAMU concept was broadened when the final CAMU rule was issued). In response to great interest in the CAMU/AOC concept as discussed in the 1990 proposal, EPA issued a fact sheet titled *Use of the Corrective Action Management Unit Concept* in August 1992 (attached). In the August, 1992 fact sheet, EPA further reiterated the AOC concept by explaining that broad areas of contamination, including specific subunits[2], could be considered landfills under the RCRA regulations and discussed activities which would or would not trigger additional RCRA requirements when conducted in such areas.

The discussions of the AOC approach in the NCP preamble, 1990 subpart S proposal, and the August, 1992 fact sheet continue to reflect EPA's interpretation of current statutory and regulatory provisions. They remain useful guidance documents when the AOC approach is

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[1] Although advance approval at the Federal level is not required for private parties to take advantage of the AOC concept, we encourage them to consult with the appropriate agency to ensure they implement the AOC concept appropriately. It should be noted that the agency responsible for determining that the AOC concept is being properly applied might not be the same as the agency overseeing cleanup at a site. Additionally, states may have more stringent standards which require consultation and/or prior approval of an AOC.

[2] Note, if the subunit were a RCRA regulated unit, inclusion of the unit within an AOC could necessitate a RCRA permit modification or a change under RCRA interim status.

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under consideration at RCRA corrective action sites, Superfund sites and during other cleanup actions involving the movement or consolidation of hazardous waste, or media and debris contaminated with hazardous waste.

Relationship of the AOC Concept to the Final CAMU Rules

On February 16, 1993, EPA published final Corrective Action Management Unit regulations (58 FR 8658, February 16, 1993). The final CAMU rule differs from the AOC approach in important respects. First, the CAMU regulations create a new type of RCRA unit - a "Corrective Action Management Unit" or "CAMU." CAMUs are distinct from the type of units listed in RCRA Section 3004(k)[3]. Second, only EPA and authorized states may choose to designate CAMUs for management of remediation waste during RCRA corrective action and other cleanups. Third, the CAMU regulations expanded the flexibility available for management of remediation wastes beyond that offered by the AOC approach. Under the CAMU regulations, certain activities which would normally be considered placement are allowed when carried out in an agency-approved CAMU, including: remediation waste[4] may be removed from a CAMU and replaced (before or after treatment) in the same or a different CAMU; remediation waste may be consolidated into a CAMU before or after treatment; and, remediation waste may be moved (again, before or after treatment) between two or more CAMUs at the same facility.

While the CAMU concept contained in the final CAMU rule was historically an outgrowth of the AOC concept, it has a separate statutory and regulatory basis; therefore, it supplements rather than supersedes the AOC concept. The AOC concept was not altered when the final CAMU rules were promulgated and it does not depend on the existence of the CAMU rule.

As you may be aware, several parties challenged the CAMU rule. The lawsuit has been stayed pending promulgation of the final Hazardous Waste Identification Rule for contaminated media ("HWIR-Media"). At the time the stay was issued, EPA stated that the HWIR-Media rule was expected to replace a substantial portion of the CAMU rule; however, as long as the CAMU rule remains in effect, CAMUs may be used to facilitate protective remedies under RCRA, CERCLA, and state cleanup authorities. If a CAMU is under consideration, we recommend you take the following steps, in addition to the CAMU approval steps required at 40 CFR § 264.552:

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[3] RCRA Section 3004(k) defines the term land disposal, when used with respect to a specified hazardous waste, to include placement of such hazardous waste in a landfill, surface impoundment, waste pile, injection well, land treatment facility, salt dome formation, salt bed formation, or underground mine or cave.

[4] Remediation waste is defined as, "all solid and hazardous wastes, and all media (including groundwater, surface water, soils, and sediments) and debris, which contain listed hazardous wastes or which themselves exhibit a hazardous waste characteristic, that are managed for the purpose of implementing corrective action requirements under 40 CFR § 264.101 and RCRA section 3008(h). For a given facility, remediation wastes may originate only from within the facility boundary, but may include wastes managed in implementing RCRA sections 3004(v) or 3008(h) for releases beyond the facility boundary.

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1) explain the potential risks associated with CAMUs to facility owner/operators by informing them that the CAMU rule has been challenged and that EPA may issue a proposal to withdraw it: 2) where possible. mitigate potential risks associated with CAMUs by. for example. implementing a CAMU remedy within the shortest possible time frame; and 3) document all CAMU decisions completely. emphasizing how the CAMU provides support for the best site-specific remedy.

Continued Use of the AOC Concept

Both AOCs and CAMUs can be used to expedite effective and protective remedial actions; however, EPA encourages the use of the AOC concept in cases where the additional flexibility provided in the final CAMU regulations is not needed. For example, the AOC concept is particularly useful for consolidation of contiguous units or areas of contaminated soil. Using the AOC concept, a RCRA facility owner/operator with a large contiguous area of soil contamination could consolidate such soils into a single area or engineered unit within an AOC without triggering the RCRA land disposal restrictions or minimum technology requirements. Use of the AOC concept would not be affected by the pending litigation over CAMU or any changes in the CAMU rule. In addition, please note, the AOC and CAMU concepts only address management of materials which would otherwise be subject to RCRA (i.e., hazardous wastes. or media and debris contaminated with hazardous waste). RCRA regulated materials are a subset of the materials managed during site cleanups.

We know you will continue to use the AOC and CAMU concepts to support appropriate remedies and to expedite cleanup processes. If you have any questions regarding the AOC or CAMU concepts. please contact Elizabeth McManus, Hugh Davis or Robin Anderson at (703) 308-8657, (703) 308-8633, and (703) 603-8747, respectively.

attachments

cc: Susan Bromm, OECA
      Elizabeth Cotsworth, OSW
      Larry Reed, OERR
      Jim Woolford, FFRRO
      Barbara Pace, OGC
      George Wyeth, OGC
      Earl Salo, OGC
      RCRA Regional Division Directors
      Superfund Regional Division Directors

United States
Environmental Protection
Agency

Office of
Solid Waste and
Emergency Response

Directive: 9347 3-05FS
July 1989

♻EPA   Superfund LDR Guide #5

Determining When Land Disposal Restrictions (LDRs) Are <u>Applicable</u> to CERCLA Response Actions

CERCLA Section 121(d)(2) specifies that on-site Superfund remedial actions shall attain "other Federal standards, requirements, criteria, limitations, or more stringent State requirements that are determined to be legally applicable or relevant and appropriate (ARAR) to the specified circumstances at the site." In addition, the National Contingency Plan (NCP) requires that on-site removal actions attain ARARs to the extent practicable. Off-site removal and remedial actions must comply with legally applicable requirements. This guide outlines the process used to determine whether the Resource Conservation and Recovery Act (RCRA) land disposal restrictions (LDRs) established under the Hazardous and Solid Waste Amendments (HSWA) are "applicable" to a CERCLA response action. More detailed guidance on Superfund compliance with the LDRs is being prepared by the Office of Solid Waste and Emergency Response (OSWER).

For the LDRs to be applicable to a CERCLA response, the action must constitute placement of a restricted RCRA hazardous waste. Therefore, site managers (OSCs, RPMs) must answer three separate questions to determine if the LDRs are applicable:

(1) Does the response action constitute placement?

(2) Is the CERCLA substance being placed also a RCRA hazardous waste? and if so

(3) Is the RCRA waste restricted under the LDRs?

Site managers also must determine if the CERCLA substances are California list wastes, which are a distinct category of RCRA hazardous wastes restricted under the LDRs (see Superfund LDR Guide #2).

(1) DOES THE RESPONSE CONSTITUTE PLACEMENT?

The LDRs place specific restrictions (e.g., treatment of waste to concentration levels) on RCRA hazardous wastes prior to their placement in land disposal units. Therefore, a key determination is whether the response action will constitute placement of wastes into a land disposal unit. As defined by RCRA, land disposal units include landfills, surface impoundments, waste piles, injection wells, land treatment facilities, salt dome formations, underground mines or caves, and concrete bunkers or vaults. If a CERCLA response includes disposal of wastes in any of these types of off-site land disposal units, placement will occur. However, uncontrolled hazardous waste sites often have widespread and dispersed contamination, making the

concept of a RCRA unit less useful for actions involving on-site disposal of wastes. Therefore, to assist in defining when "placement" does and does not occur for CERCLA actions involving on-site disposal of wastes, EPA uses the concept of "areas of contamination" (AOCs), which may be viewed as equivalent to RCRA units for the purposes of LDR applicability determinations.

An AOC is delineated by the areal extent (or boundary) of contiguous contamination. Such contamination must be continuous, but may contain varying types and concentrations of hazardous substances. Depending on site characteristics, one or more AOCs may be delineated. Highlight 1 provides some examples of AOCs.

> **Highlight 1: EXAMPLES OF AREAS OF CONTAMINATION (AOCs)**
>
> - A waste source (e.g., waste pit, landfill, waste pile) and the surrounding contaminated soil.
>
> - A waste source, and the sediments in a stream contaminated by the source, where the contamination is continuous from the source to the sediments.*
>
> - Several lagoons separated only by dikes, where the dikes are contaminated and the lagoons share a common liner.
>
> _____
> * The AOC does not include any contaminated surface or ground water that may be associated with the land-based waste source.

For on-site disposal, placement occurs when wastes are moved from one AOC (or unit) into another AOC (or unit). Placement does not occur when wastes are left in place, or moved within a single AOC. Highlight 2 provides scenarios of when placement does and does not occur, as defined in the proposed NCP. The Agency is current reevaluating the definition of placement prior to the promulgation of the final NCP, and therefore, these scenarios are subject to change.

the two types of RCRA hazardous wastes — listed and characteristic wastes.

Highlight 2: PLACEMENT

Placement does occur when wastes are:

- Consolidated from different AOCs into a single AOC;

- Moved outside of an AOC (for treatment or storage, for example) and returned to the same or a different AOC; or

- Excavated from an AOC, placed in a separate unit, such as an incinerator or tank that is within the AOC, and redeposited into the same AOC.

Placement does not occur when wastes are:

- Treated in situ;

- Capped in place;

- Consolidated within the AOC; or

- Processed within the AOC (but not in a separate unit, such as a tank) to improve its structural stability (e.g., for capping or to support heavy machinery).

Highlight 3: RCRA HAZARDOUS WASTES

A RCRA solid waste* is hazardous if it is listed or exhibits a hazardous characteristic.

Listed RCRA Hazardous Wastes

Any waste listed in Subpart D of 40 CFR 261, including:

- F waste codes (Part 261.31)

- K waste codes (Part 261.32)

- P waste codes (Part 261.33(e))

- U waste codes (Part 261.33(f))

Characteristic RCRA Hazardous Wastes
Any waste exhibiting one of the following characteristics, as defined in 40 CFR 261:

- Ignitability

- Corrosivity

- Reactivity

- Extraction Procedure (EP) Toxicity

---

* A solid waste is any material that is discarded or disposed of (i.e., abandoned, recycled in certain ways, or considered inherently waste-like). The waste may be solid, semi-solid, liquid, or a contained gaseous material. Exclusions from the definition (e.g., domestic sewage sludge) appear in 40 CFR 261.4(a). Exemptions (e.g., household wastes) are found in 40 CFR 261.4(b).

In summary, if placement on-site or off-site does not occur, the LDRs are not applicable to the Superfund action.

(2) IS THE CERCLA SUBSTANCE A RCRA HAZARDOUS WASTE?

Because a CERCLA response must constitute placement of a restricted RCRA hazardous waste for the LDRs to be applicable, site managers must evaluate whether the contaminants at the CERCLA site are RCRA hazardous wastes. Highlight 3 briefly describes

Site managers are not required to presume that a CERCLA hazardous substance is a RCRA hazardous waste unless there is affirmative evidence to support such a finding. Site managers, therefore, should use "reasonable efforts" to determine whether a substance is a RCRA listed or characteristic waste. (Current data collection efforts during CERCLA removal and

remedial site investigations should be sufficient for this purpose.) For listed hazardous wastes, if manifests or labels are not available, this evaluation likely will require fairly specific information about the waste (e.g., source, prior use, process type) that is "reasonably ascertainable" within the scope of a Superfund investigation. Such information may be obtained from facility business records or from an examination of the processes used at the facility. For characteristic wastes, site managers may rely on the results of the tests described in 40 CFR 261.21 - 261.24 for each characteristic or on knowledge of the properties of the substance. Site managers should work with Regional RCRA staff, Regional Counsel, State RCRA staff, and Superfund enforcement personnel, as appropriate, in making these determinations.

In addition to understanding the two categories of RCRA hazardous wastes, site managers will also need to understand the derived-from rule, the mixture rule, and the contained-in interpretation to identify correctly whether a CERCLA substance is a RCRA hazardous waste. These three principles, as well as an introduction to the RCRA delisting process, are described below.

Derived-from Rule (40 CFR 261.3(c)(2))

The derived-from rule states that any solid waste derived from the treatment, storage, or disposal of a listed RCRA hazardous waste is itself a listed hazardous waste (regardless of the concentration of hazardous constituents). For example, ash and scrubber water from the incineration of a listed waste are hazardous wastes on the basis of the derived-from rule. Solid wastes derived from a characteristic hazardous waste are hazardous wastes only if they exhibit a characteristic.

Mixture Rule (40 CFR 261.3(a)(2))

Under the mixture rule, when any solid waste and a listed hazardous waste are mixed, the entire mixture is a listed hazardous waste. For example, if a generator mixes a drum of listed F006 electroplating waste with a non-hazardous wastewater (wastewaters are solid wastes - see Highlight 3), the entire mixture of the F006 and wastewater is a listed hazardous waste.

Mixtures of solid wastes and characteristic hazardous wastes are hazardous only if the mixture exhibits a characteristic.

Contained-in Interpretation (OSW Memorandum dated November 13, 1986)

The contained-in interpretation states that any mixture of a non-solid waste and a RCRA listed hazardous waste must be managed as a hazardous waste as long as the material contains (i.e., is above health-based levels) the listed hazardous waste. For example, if soil or ground water (i.e., both non-solid wastes) contain an F001 spent solvent, that soil or ground water must be managed as a RCRA hazardous waste, as long as it "contains" the F001 spent solvent.

Delisting (40 CFR 260.20 and .22)

To be exempted from the RCRA hazardous waste "system," a listed hazardous waste, a mixture of a listed and solid waste, or a derived-from waste must be delisted (according to 40 CFR 260.20 and .22). Characteristic hazardous wastes never need to be delisted, but can be treated to no longer exhibit the characteristic. A contained-in waste also does not have to be delisted; it only has to "no longer contain" the hazardous waste.

If site managers determine that the hazardous substance(s) at the site is a RCRA hazardous waste(s), they should also determine whether that RCRA waste is a California list waste. California list wastes are a distinct category of RCRA wastes restricted under the LDRs (see Superfund LDR Guide #2).

(3)   IS THE RCRA WASTE RESTRICTED UNDER THE LDRs?

If a site manager determines that a CERCLA waste is a RCRA hazardous waste, this waste also must be restricted for the LDRs to be an applicable requirement. A RCRA hazardous waste becomes a restricted waste on its HSWA statutory deadline or sooner if the Agency promulgates a standard before the deadline. Because the LDRs are being phased in over a period of time (see Highlight 4), site managers may need to determine what type of restriction is in

<table>
<tr><td colspan="2">Highlight 4: LDR STATUTORY DEADLINES</td></tr>
<tr><td>Waste</td><td>Statutory Deadline</td></tr>
<tr><td>Spent Solvent and Dioxin-Containing Wastes</td><td>November 8, 1986</td></tr>
<tr><td>California List Wastes</td><td>July 8, 1987</td></tr>
<tr><td>First Third Wastes</td><td>August 8, 1988</td></tr>
<tr><td>Spent Solvent, Dioxin-Containing, and California List Soil and Debris From CERCLA/RCRA Corrective Actions</td><td>November 8, 1988</td></tr>
<tr><td>Second Third Wastes</td><td>June 8, 1989</td></tr>
<tr><td>Third Third Wastes</td><td>May 8, 1990</td></tr>
<tr><td>Newly Identified Wastes</td><td>Within 6 months of identification as a hazardous waste</td></tr>
</table>

effect at the time placement is to occur. For example, if the RCRA hazardous wastes at a site are currently under a national capacity extension when the CERCLA decision document is signed, site managers should evaluate whether the response action will be completed before the extension expires. If these wastes are disposed of in surface impoundments or landfills prior to the expiration of the extension, the receiving unit would have to meet minimum technology requirements, but the wastes would not have to be treated to meet the LDR treatment standards.

APPLICABILITY DETERMINATIONS

If the site manager determines that the LDRs are applicable to the CERCLA response based on the previous three questions, the site manager must (1)

comply with the LDR restriction in effect, (2) comply with the LDRs by choosing one of the LDR compliance options (e.g., Treatability Variance, No Migration Petition), or (3) invoke an ARAR waiver (available only for on-site actions). If the LDRs are determined not to be applicable, then, for on-site actions only, the site manager should determine if the LDRs are relevant and appropriate. The process for determining whether the LDRs are applicable to a CERCLA action is summarized in Highlight 5.

Highlight 5 - DETERMINING WHEN LDRS ARE APPLICABLE REQUIREMENTS

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

AUG 31 1992

MEMORANDUM

SUBJECT: Use of the Corrective Action Management Unit (CAMU) Concept

TO: Waste Management Division Directors, Regions I - X
RCRA Branch Chiefs, Regions I - X
RCRA Regional Counsel, Regions I - X

FROM: Sylvia Lowrance, Director
Office of Solid Waste

Bruce Diamond, Director
Office of Waste Programs Enforcement

At the February 1992 Stabilization Conference in Colorado Springs we discussed the possibility of implementing the corrective action management unit (CAMU) concept before final promulgation of the Subpart S regulations. At that time OSWER made a commitment to provide further guidance to the Regions on how to use existing RCRA regulations to achieve some of the remedial benefits of the CAMU. The attached document, "Use of the Corrective Action Management Unit Concept," provides that guidance.

The CAMU portion of Subpart S is on a current schedule to be finalized by December 1992. The attached guidance, which was developed jointly by OSWER and OGC, clarifies the Agency's legal authority for utilizing a CAMU-like approach before the CAMU rule is finalized, and provides guidance on when and how to use the concept. The concept can be applied during final remedies, and in the implementation of stabilization actions to reduce imminent threats and contain releases. We encourage the use of this concept whenever the success of the remedial option at a particular facility will be enhanced.

If you have any questions regarding the content of this guidance, please call Dave Fagan at (202) 260-4497.

cc: Lisa Friedman, OGC
Henry Longest, OERR
Kathie Stein, OE

♳EPA — Use of the Corrective Action Management Unit Concept

Office of Solid Waste

BACKGROUND

Beginning in 1992, EPA began implementing a new strategy to increase the pace of cleanup and to achieve positive environmental results at RCRA treatment, storage and disposal facilities (TSDFs) requiring corrective action. While comprehensive facility cleanup is still the long-term goal for the RCRA Corrective Action Program, this new initiative emphasizes the importance of stabilizing sites by controlling releases and preventing the further spread of contaminants.

At most RCRA facilities, stabilization or final remedial actions will involve excavation and on-site management of contaminated soils, sludges and other wastes that are subject to the RCRA Subtitle C hazardous waste regulations. In these situations, a number of issues can arise regarding the applicability of certain RCRA requirements, and how these requirements may affect the remedial activities. Specifically, experience in the RCRA and CERCLA remedial programs has shown that the RCRA land disposal restrictions (LDRs) and minimum technology requirements (MTRs) may limit the types of remedial options available at sites, as well as affect the types of specific technologies that may be used, the volume of materials that are managed, and other features of remedies under consideration.

Recognizing that strict application of these RCRA requirements may limit or constrain desirable remedies, including stabilization programs, EPA is developing an important regulatory concept, known as the Corrective Action Management Unit (CAMU), to facilitate effective and protective remedial actions. This concept, first discussed in the proposed Subpart S corrective action regulations (55 FR 30798, July 27, 1990), is similar to the Superfund concept of the "area of contamination," in which broad areas of contamination, often including specific subunits, are considered to be a single land disposal unit for remedial purposes.

CAMUs may be particularly useful for specific remedial activities such as consolidation of units or contaminated surficial soils. For example, a group of unlined inactive lagoons that are continuing sources of releases to groundwater may be best remediated by removing and treating the concentrated wastes in another unit, and excavating the remaining low-concentration contaminated soils from underneath the lagoons. These soils could then be consolidated and placed into a protective and cost-effective single-capped unit, thereby controlling further releases to groundwater. In other situations site remediations will require excavation of large quantities of relatively low-level contaminated surficial soils. In these cases a protective and cost-effective remedy might be to excavate the soils and consolidate them into a single area or engineered unit within the area of contamination. For both of these examples, application of LDRs and possibly MTR requirements would result in a more costly and complex remedy, that may delay remediation and result in little additional environmental protection for the site.

As proposed in the Subpart S rule, there may be certain types of situations in which application of the CAMU concept (55 FR 30842) would be inappropriate. In addition, several

factors (55 FR 30883) may be considered by decision-makers in determining how CAMUs would actually be designated at sites. Although owner/operators may propose a specific area as a CAMU, it is the responsibility of EPA or the authorized State to determine whether a CAMU is necessary and appropriate, and, if so, to determine the boundaries of the unit.

The Subpart S regulations have not yet been finalized. However, although the CAMU concept has been presented only in proposed regulations, existing regulatory authority may be used to implement this type of approach in site remediations and stabilization actions. The Agency's experience with the RCRA and CERCLA remedial programs indicates that the CAMU concept could be applied immediately to great advantage at a significant number of RCRA cleanup sites. This guidance is presented to clarify the use of the CAMU concept prior to final regulations.

USE OF LANDFILL DESIGNATION FOR REMEDIAL PURPOSES

Specifically, certain contaminated areas at sites that require remediation, including groups of units in such areas, may be designated as a "landfill" under the current RCRA landfill definition (40 CFR § 260.10). Designating such an area of a facility as a landfill within the existing regulatory framework can achieve remedial benefits similar to those that would be obtained by using CAMUs under the Subpart S proposal. Prior to the promulgation of final CAMU rules, EPA encourages the use of this approach at contaminated sites, where it can promote effective and expeditious remedial solutions. EPA recommends that decisions on designating certain contaminated areas or groups of units as a landfill be made in accordance with applicable regulations and generally in accordance with the CAMU provisions in the Subpart S proposal.

Owner/operators proposing to address certain areas at a facility as a single landfill for remedial purposes should request approval from EPA or the authorized State agency. The Regional Administrator or the authorized State Director will be the ultimate decision-maker as to whether such a landfill unit will help achieve the remedial objectives at the facility. EPA recommends decisions to use existing authorities, waivers, or variances to achieve many of the same objectives as the proposed Subpart S rule CAMU provisions should generally follow the proposed regulatory provisions (55 FR 30883) and preamble

discussion (55 FR 30842) in defining the boundaries of the remedial unit. The Region or authorized State may also look to Superfund guidance in the designation of AOCs (55 FR 8758-8760).

Designating an area of contamination as a "landfill" will require that the unit comply with certain RCRA requirements that are applicable to landfills. The specific requirements that apply will differ, depending on whether the landfill is considered to be: (1) an existing non-regulated landfill, or (2) a regulated hazardous waste landfill. This distinction is determined by the regulatory status of the units or areas that are included as part of the landfill. The following discussion explains further the requirements associated with these two types of landfills.

Existing Non-Regulated Landfills

Figure 1 shows an area of contamination at a facility that includes several land-based solid waste management units (SWMUs) that are not regulated as hazardous waste units under RCRA (e.g., because all of the disposal occurred before the RCRA hazardous waste regulations went into effect). By designating this area as a single landfill, EPA can approve movement and consolidation of hazardous wastes and soils contaminated with hazardous waste within the unit boundary, without triggering the LDRs or MTRs. For example, contaminated soils in and around SWMUs 1 and 2 could be consolidated into SWMU 3 and capped without triggering LDR requirements.

This landfill would not be subject to the RCRA Part 264 or Part 265 design and operating requirements for hazardous waste landfills. This is because the landfill would not have received hazardous waste after November 19, 1980. (See 40 CFR § 270.1(c)). In the absence of specific Part 264 or 265 requirements for such units, appropriate ground water monitoring and closure requirements for the landfill can be determined by EPA or the State as part of the corrective action remedial decision-making process. These requirements would be based on an assessment of site specific factors, such as waste characteristics, site hydrogeology, exposure potential, and other factors. This allows the regulator further flexibility in designing remedial solutions which are effective and protective based on actual site conditions.

These non-regulated landfills would remain exempt from regulation under Parts 264 and 265, under the following circumstances:

FIGURE 1
EXISTING NON-REGULATED LANDFILL

Tank

SWMU 2

SWMU 3

SWMU 1

Contaminated Soil

Facility Boundary

Uncontaminated Soil

- The landfill cannot receive hazardous waste from other units, either on-site or off-site. The landfill could, however, receive non-hazardous waste as part of the cleanup actions. If it were to receive hazardous waste, the landfill would become a regulated unit (40 CFR § 270.1(c)) subject to the requirements of Subparts F (40 CFR § 264.90) and G (40 CFR § 264.110). The facility permit would have to be modified accordingly (for interim status facilities, a change would have to be approved under 40 CFR § 270.72), and the waste would have to be treated to comply with applicable LDR standards prior to placement in the landfill.

- If hazardous waste treatment (including in-situ treatment) takes place within the landfill, the owner/operator must comply with all Part 264 or 265 requirements applicable to the treatment unit, and must modify the permit or Part A to include the new treatment unit.

- Similarly, residuals from treatment of hazardous wastes that have been removed from the landfill and treated in a non-

land-based unit cannot be redeposited into the landfill unless the residuals meet the LDRs. If the residuals were still hazardous by characteristic or still contained hazardous waste, disposal of the residuals into the landfill would require the landfill to be designated a "regulated unit," as the unit would have received hazardous waste after July 26, 1982.

- Hazardous wastes transferred from the non-regulated landfill to another land-based unit would also have to meet LDR standards.

Regulated Landfills

Figure 2 shows an area of contamination that could be designated as a landfill, which contains two regulated units (as defined in 40 CFR § 264.90). As with the previous example in Figure 1, designating this area as a landfill would allow wastes to be moved and consolidated within the area without triggering the LDRs. However, because this landfill contains regulated units, the entire area must be considered a regulated unit. Accordingly, the following requirements would apply:

FIGURE 2
REGULATED LANDFILL

Tank

RU

RU

Surface Impoundments

SWMU

Contaminated Soil

SWMU

Facility Boundary

Uncontaminated Soil

- The unit boundaries of the original regulated units that were specified on the Part A or Part B application would have to be redesignated to encompass the entire new landfill unit, according to the applicable procedures in 40 CFR §§ 270.72, 270.41 or 270.42.

- The landfill would have to comply with applicable Part 264 or 265 requirements for landfills, including the Subpart F ground water monitoring requirements and Subpart G closure and post-closure requirements. Subpart F requirements would generally involve installation of additional ground water monitoring wells. Compliance with Subpart G would likely also require modifications to the closure and post-closure plans for the unit.

MTRs would not necessarily apply to these newly designated regulated landfills. If the original regulated unit located within the landfill was not subject to the MTRs (i.e., the landfill was not new or expanding after 1984), the landfill could be considered by the Agency or authorized State to be a redesignation of that existing unit, rather than a lateral expansion. As such, the landfill would not be subject to the MTRs. However, if the regulated unit encompassed by the landfill was originally subject to MTRs, the entire area of the landfill would be subject to MTRs.

SUMMARY

Existing regulatory standards (e.g., replacement of treatment residuals into the CAMU triggers the LDRs) cannot be waived to implement the CAMU concept prior to a final CAMU rulemaking. EPA is considering removing some of these limitations in the final rule. Nonetheless, despite these current limitations, there may be a number of situations where the use of landfills can yield substantial benefits in remediating sites. EPA recommends that the guidance provided in this fact sheet be used in evaluating the use of landfills to implement timely and protective corrective actions at RCRA facilities.

FOR FURTHER INFORMATION

Inquiries concerning the guidance contained in this fact sheet should be directed to Dave Fagan (202) 260-4497, or Anne Price (202) 260-6725.

4

United States Environmental Protection Agency
Washington, D.C. 20460
Office of Solid Waste and Emergency Response

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cc: Lisa Friedman, OGC; Henry Longest, OERR; Kathie Stein, OE

Enclosure

Use of the Corrective Action Management Unit Concept

United States Environmental Protection Agency
Washington, D.C. 20460
Office of Solid Waste and Emergency Response

August 1992

Background

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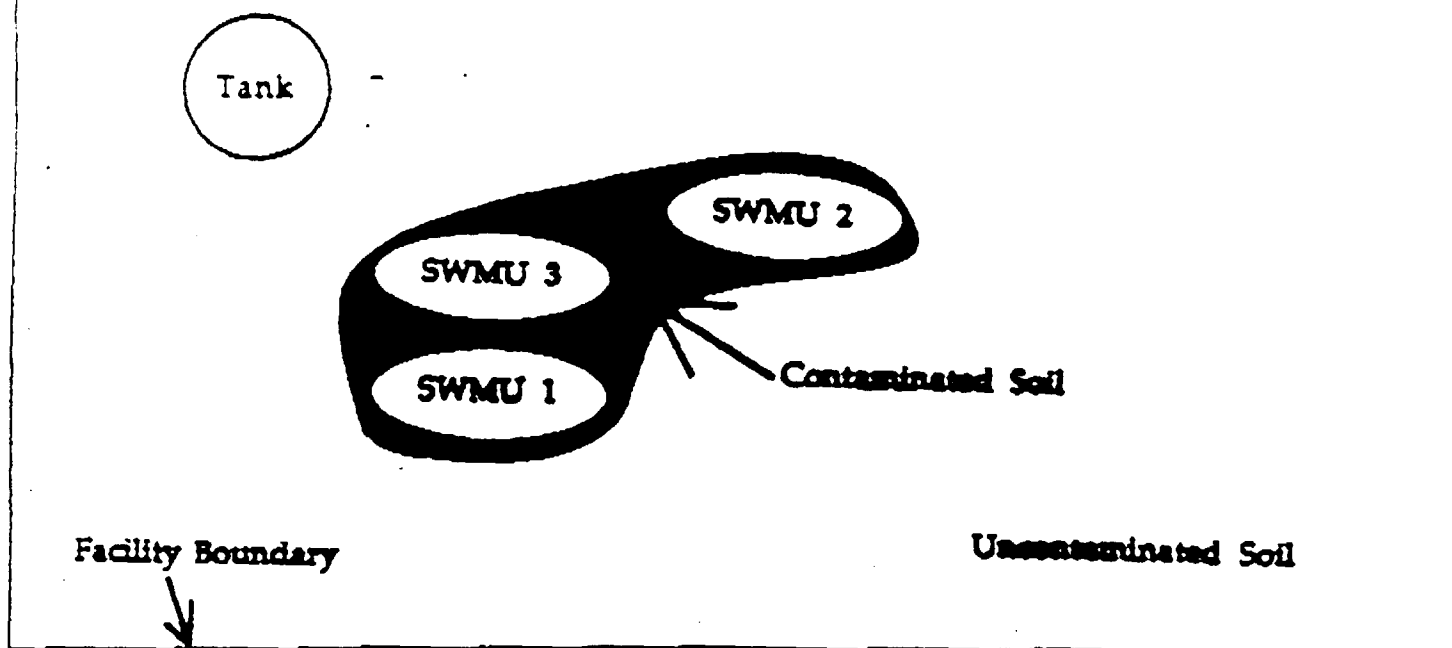
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This landfill would not be subject to the RCRA Part 264 or Part 265 design and operating requirements for hazardous waste landfills. This is because the landfill would not have received hazardous waste after November 19, 1980. (See 40 CFR 270.1(c)). In the absence of specific Part 264 or 265 requirements for such units, appropriate ground water monitoring and closure requirements for the landfill can be determined by EPA or the State as part of the corrective action remedial decision-making process. These requirements would be based on an assessment of site specific factors, such as waste characteristics, site hydrogeology, exposure potential, and other favors. This allows the regulator further flexibility in designing remedial solutions which are effective and protective based on actual site conditions.

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- Similarly, residuals from treatment of hazardous wastes that have been removed from the landfill and treated in a non-land-based unit cannot be redeposited into the landfill unless the residuals meet the LDRs. If the resiouals were still hazardous by characteristic or still contained hazardous wastes, disposal of the residuals into the landfill would require the landfill to be designated a "regulated unit," as the unit would have received hazardous waste after July 26, 1982.

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Summary

Existing regulatory standards (e.g., replacement of treatment residuals into the CAMU triggers the LDRs) cannot be waived to implement the CAMU concept prior to a final CAMU rulemaking. EPA is considering removing some of these limitations in the final rule. Nonetheless, despite these current limitations, there may be a number of situations where the use of landfills can yield substantial benefits in remediating sites. EPA recommends that the guidance provided in this fact sheet be used in evaluating the use of landfills to implement timely and protective corrective actions at RCRA facilities.

For Further Information

Inquiries concerning the guidance contained in this fact sheet should be directed to Dave Fagan (202) 260-4497, or Anne Price (202) 260-6725.

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

OCT 29 1992

Mr. Richard S. Wasserstrom
Miles and Stockbridge
Metropolitan Square
1450 G Street, NW, Suite 445
Washington, DC 20005

Dear Mr. Wasserstrom:

This is in response to your letter of September 10, 1992, in which you wanted a clarification of the "no land disposal" condition as it applies to the recycling of coke by-product residues (40 CFR 261.4(a)(10)). Specifically, you want to know in what kinds of units recycling operations can be performed (prior to the residuals being reinserted into a coke oven or mixed with coal tar) and still qualify for this no land disposal condition.

The Agency agrees with your concern that some members of the regulated community may not be complying properly with the no land disposal provision in the coke by-products recycling exclusion. Briefly, the Agency intends for facilities in the coke by-products industry to be able to recycle hazardous wastes to coke ovens, the tar recovery process, or coal tar. During the development of the final coke rules (57 FR 27880, June 22, 1992, and 57 FR 37284, August 18, 1992), the Agency researched recycling of these residuals and determined that the technology existed to recycle several residuals in this industry without the residuals becoming part of the "waste disposal problem" (57 FR 27880), and thus promulgated the recycling exclusion for coke by-products wastes.

Using the wrong kind of unit for recycling can lead to waste becoming a disposal problem. In particular, open pits or flat or low-walled concrete pads that do not contain the recycled materials effectively are not units that qualify for the recycling exclusion. Where the waste is managed on the ground, or the construction of the unit causes the waste(s) to spill or otherwise be disposed onto the ground, the Agency feels that those units or facilities are inadequate to perform the recycling task without the wastes being land disposed. However, tanks, containers, and (as you pointed out) containment buildings, when they are designed properly to keep the recycled materials from being emitted beyond the zone of engineering controls, are units that qualify for the recycling exclusion.

The Agency feels that, for the recycling of wastes in this industry, certain criteria must be met. The units used in the recycling operations must be able to keep the recycled materials contained by being properly sealed (in the case of concrete units) or welded (in the case of metal units). The operators must perform the operations in such a way as to prevent releases of recycled materials. Operators of the recycling units must comply with all other applicable requirements, as well (e.g., air emissions, run-on/run-off, etc.)

You should be aware of some factors that may affect the implementation of the rule in specific areas. Some States might not adopt the recycling provisions of the coke rule as promulgated on August 18, 1992, so regulation of the wastes from this industry may be more strictly controlled. In addition, the determination as to whether a specific tank, container, containment building, or other unit meets State design criteria for "no land disposal" is site-specific, and may vary from place to place. While the Agency clearly intends for the units to contain the wastes adequately, the Agency leaves the creation of such site-specific criteria to local authorities. Clearly, the Agency does not want to limit the possibility for future process changes that may lead to the recycling of coke by-products wastes in a more efficient manner by setting inflexible guidelines.

Thank you for your inquiry. If you need any further assistance on this topic, please contact Ron Josephson of my staff at (202)260-4770 or the EPA Regional Office or State agency responsible for implementing the regulations on recyclables.

Sincerely,

Sylvia K. Lowrance
Director
Office of Solid Waste

bcc: Steve Silverman, OGC (LE-132S)
     Ken Gigliello, OWPE (OS-520)
     Waste Management Division Directors, Regions II-VI, VIII

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September 10, 1992

Ms. Sylvia K. Lowrance
Director
Office of Solid Waste (OS-300)
Environmental Protection Agency
401 M Street, SW
Washington, DC 20460

Re: Request for interpretation of the "no land disposal"
condition of the coke by-product recycling exclusion.

Dear Ms. Lowrance:

We have been asked by a client to obtain the Agency's
written confirmation that the "no land disposal" condition of the
40 C.F.R. § 261.4(a)(10) exclusion of certain recycled coke by-
products from the definition of solid waste precludes excluded
status for wastes managed on concrete pads, because such
management constitutes a waste pile -- a form of land disposal.

As we understand the "no land disposal" condition, it
requires that the by-products must be managed in tanks,
containers, or containment buildings (the latter effective on
November 16, 1992) from the point of generation until the
recycled material is mixed with coal for recharging to the coke
oven or mixed with coal tar.

EPA recently issued a rule, which excludes from the
definition of solid waste certain coke by-products

> when, subsequent to generation, these materials are
> recycled to coke ovens, to the tar recovery process as
> a feedstock to produce coal tar, or mixed with coal tar
> prior to the tar's sale or refining. This <u>exclusion is
> conditioned on there being no land disposal of the
> wastes from the point they are generated to the point
> they are recycled to coke ovens or tar recovery or
> refining processes, or mixed with coal tar.</u>

57 Fed. Reg. 37284, 37305 (Aug. 18, 1992) (to be codified at 40 C.F.R. § 261.4(a)(10)) (emphasis added). EPA adopted an earlier version of this exclusion at 57 Fed. Reg. 27880, 27888 (June 22, 1992).

We believe that the "no land disposal" condition is crystal clear; only tanks, containers or containment buildings as those terms are defined at 40 C.F.R. § 260.10, as amended, may be used to manage excluded coke by-product wastes. However, there appears to be some confusion in the regulated community about the "no land disposal" criterion; in particular, some believe that the "no land disposal" condition is satisfied if the wastes are managed on concrete pads. These pads are generally slabs of concrete, which are located outdoors. Some are open-sided (i.e., have no containment); others may have shallow berms or low walls, which range from a few inches to four feet high, on one or more -- but not all -- sides. Recycling is practiced on these pads by placing hazardous waste coke by-products and coal onto the pads and mixing them by mechanical means, such as backhoes, front end loaders, or bulldozers, which enter and exit the pad area via the open side. The mixed material is then conveyed to coke ovens.

As we understand EPA's hazardous waste rules, these concrete pads are waste piles, a form of land disposal. 40 C.F.R. § 268.2(c). See also 40 C.F.R. § 265.253 (requiring that certain waste piles "must be placed on an impermeable base"). Our understanding is confirmed by the Land Disposal Restrictions for Newly Listed Wastes and Hazardous Debris rule published August 18, 1992 at 57 Fed. Reg. 37194. In this rule, EPA established "containment buildings" as a new waste management unit, which would allow storage or treatment of hazardous wastes without land disposal. Id. at 37211. Such units were necessary, EPA explained, because hazardous wastes generated in large volumes

> may not be amenable to management in RCRA tanks or containers [and] are sometimes stored or treated on concrete pads or similar floors inside buildings. EPA currently classifies this type of management unit as an indoor waste pile, which EPA considers to be a land disposal unit based on the statutory definition of land disposal in section 3004(k).

Id. (emphasis added).

The August 1, 1992 Background Document for these rules also confirms that management of coke by-product wastes on concrete pads is land disposal. It states that "[m]aterials that are stored in piles on the land are thus considered to be solid wastes and are not excluded from regulation." Background
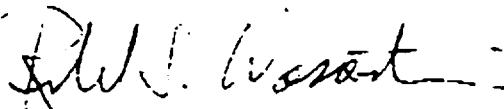
Document at 70. Moreover, the Background Document states that placement of hazardous coke by-products on low-walled concrete pads does not comply with the land disposal restrictions:

> To comply with the Land Disposal Restrictions (LDR, 40 CFR Part 268), many facilities have had to discontinue placing K087 wastes on the ground, in a pit, or on a low-walled concrete pad to mix these wastes with coal. Instead, these wastes must be managed in a unit such as a tank to accommodate K087 (and other) wastes. For facilities without such units, the Agency believes that recycling the wastes without land placement will cause minimal extra requirements over and above what already exists.

Id. at 77-78 (emphasis added). Notwithstanding such agency guidance, some in the regulated community are apparently not aware that management of hazardous coke by-products on concrete pads is land disposal and is, therefore, not eligible for exempt status under § 261.4(a)(10).

Accordingly, we request that the Agency issue a letter confirming that § 261.4(a)(10) as recently amended excludes from the definition of solid waste only those coke by-products that are recycled in tanks, containers, or containment buildings, and that placement of such by-product material on concrete pads disqualifies the recycled material from the exclusion.

Sincerely,

Richard S. Wasserstrom

RSW:jo

cc: Steven E. Silverman, Esq.
    Ron Josephson

RSW2/Lowrance.LDR

Appendix 4-F

Order of Magnitude
Cost Estimates

Appendix 4-F

Order of Magnitude Cost Estimate
Vadose Zone Soil

Alternative 3

• Asphalt Cap

Applicable Media:
PAH Remediation Zone soil, Arsenic Remediation Zone soil, Marginal Zone Soil

Description:
Asphalt driving surface suitable for limited driving which will prohibit contact with subsurface soils and reduce/eliminate infiltration through paved areas and promote runoff.

Cost Estimate:

Item	Quantity	Units	Unit Cost	Cost
Move Soils from Designated Stockpile	5,000	CY	$5	$25,000
HDPE Geomembrane	575,000	SF	$0.85	$489,000
Subbase	21,500	CY	$15	$323,000
Asphalt	575,000	SF	$2	$1,150,000
Stormwater Detention Pond	1	LS	$550,000	$550,000
Site Restoration	1	LS	$100,000	$100,000
O&M–Maintain Cover ($5,000/yr. for 30 yrs. at 5%)	1	LS	$77,000	$77,000
			Subtotal	$2,714,000
Mobilization/Demobilization, Engineering, and Contingencies (50%)				$1,357,000
			Total	**$4,100,000**

Assumptions:

• Pavement design will allow moderate traffic on the surface for parking or storage.
• Requires maintenance and repair over the long term.
• Runoff from cap area drains to perimeter for re-infiltration.
• Asphalt cap is approximately 13.2 acres, with 12 inches of subbase, and 3 inches of asphalt.

Order of Magnitude Cost Estimate

Alternative 4a

- **On-Site Containment Unit for PAH Remediation Zone and Arsenic Remediation Zone Soil**
- **Asphalt/Building Cap**

Applicable Media:
PAH Remediation Zone soil, Arsenic Remediation Zone soil, Marginal Zone Soil

Description:
Disposal of contaminated soil in an on-site RCRA-style containment unit. The containment unit includes a double-synthetic liner with a leachate collection system and a synthetic liner with soil and vegetation for the final cover. The containment unit acts as a portion of the cap, and an asphalt parking surface caps the remainder. The asphalt cap will prohibit contact with subsurface soils and reduce infiltration through paved areas and promote runoff. The containment unit will require postclosure monitoring.

Cost Estimate:

Item	Quantity	Units	Unit Cost	Cost
Containment Unit				
Excavation and Placement of Soil in Containment Unit, Management of Debris	18,000	CY	$35	$630,000
Construct On-Site Containment Unit	1	LS	$1,000,000	$1,000,000
Site Work, Subgrade Preparation	1	LS	$800,000	$800,000
Haul and Compact Soil for Backfill, Site Restoration	1	LS	$200,000	$200,000
O&M of Landfill ($40,000/year, 30 yrs., 5% interest)	1	LS	$800,000	$800,000
Subtotal: On-Site Containment Unit				$3,430,000

Asphalt Cap				
HDPE Geomembrane	355,000	SF	$0.85	$302,000
Subbase	13,500	CY	$15	$203,000
Asphalt	355,000	SF	$2	$710,000
Site Restoration	1	LS	$100,000	$100,000
Stormwater Detention Pond	1	LS	$550,000	$550,000
O&M–Maintain Cover, ($5,000/yr. for 30 yrs. at 5%)	1	LS	$77,000	$77,000
Subtotal: Asphalt Cap				$1,942,000
Itemized Total				$5,372,000
Mobilization/Demobilization, Engineering, and Administration (See Note 1)				$2,686,000
Total				$8,100,000

Note 1: Mob/Demob, Engineering and Administration is based on 50 percent of the on site work.

Assumptions:
- Double synthetic liner construction with leachate collection for containment unit.
- Synthetic liner, perforated drain tile, gas vents, and vegetation for cover.
- Includes cost to over-excavate and place select material for liner system foundation.
- Estimate does not include site monitoring: groundwater monitoring for the site, regulatory oversight, annual report, and five-year review. This is included in the groundwater cost estimate.
- O&M includes monitoring for the containment unit, leachate collection and treatment, equipment replacement, maintain final cover, leachate pipe cleaning and pump maintenance.
- Pavement design will allow moderate traffic on the surface for parking or storage.
- Requires maintenance and repair over the long term.
- Runoff from cap area drains to stormwater detention pond.
- Soil density of 1.5 tons/cy.
- Containment unit volume = 18,000 cy (7,100 cy of PAH Remediation Zone soil, 3,300 cy of Arsenic Remediation Zone soil, and 50% allowance for excess contaminated soil).
- PAH Remediation Zone soil excavation volume = 14,300 cy, of which 7,100 cy is placed in the containment unit, and 7,200 cy is overburden material which is used as backfill.
- Arsenic Remediation Zone soil excavation volume = 3,300 cy.
- Overlap soil unaccounted for due to small overlap area.
- Vault is approximately 400 ft by 550 ft and has a maximum capacity of 18,000 cy.
- Asphalt cap area is approximately 9.6 acres (cap is reduced by the area of the containment unit).

Order of Magnitude Cost Estimate

Alternative 4b

- **Off-Site Disposal of PAH Remediation Zone and Arsenic Remediation Zone Soils**
- **Asphalt/Building Cap**

Applicable Media:
PAH Remediation Zone soil, Arsenic Remediation Zone soil, Marginal Zone Soil

Description:
Transportation of soil to a permitted RCRA Subtitle C Landfill for Hazardous Waste, and installing asphalt parking surface which will prohibit contact with subsurface soils and reduce infiltration through paved areas and promote runoff.

Cost Estimate:

Item	Quantity	Units	Unit Cost	Cost
Off-Site Disposal: Arsenic and PAH Remediation Zone Soil				
Excavation, Segregation, Loading, and Debris Management	18,000	CY	$35	$630,000
Transportation	16,000	Ton	$30	$480,000
Sampling/Testing	16,000	Ton	$10	$160,000
Disposal at RCRA Subtitle C Landfill	16,000	Ton	$120	$1,920,000
Move Soils from Designated Stockpile	5,000	CY	$5	$25,000
Backfill and Compact Borrow Material	13,000	CY	$15	$195,000
Subtotal: Off-Site Disposal				$3,410,000
Asphalt Cap				
HDPE Geomembrane	575,000	SF	$0.85	$489,000
Subbase	21,500	CY	$15	$323,000
Asphalt	575,000	SF	$2	$1,150,000
Site Restoration	1	LS	$100,000	$100,000
Stormwater Detention Pond	1	LS	$550,000	$550,000
O&M–Maintain Cover, ($5,000/yr. for 30 yrs. at 5%)	1	LS	$77,000	$77,000
Subtotal: Asphalt Cap				$2,689,000
Itemized Total				$6,099,000
Mobilization/Demobilization, Engineering, and Administration (See Note 1)				$2,450,000
Total				**$8,500,000**

Note 1:   Mob/Demob, Engineering and Administration is based on 50 percent of the on site work and 25 percent for the transportation and disposal costs.

Assumptions:

- Soil density of 1.5 tons/cy.
- Pavement design will allow moderate traffic on the surface for parking or storage.
- Requires maintenance and repair over the long term.
- Runoff from cap area drains to stormwater detention pond.
- Disposal at PDC facility in Peoria, IL.
- PAH and Arsenic Remediation Zone soil excavation and segregation volume = 18,000 cy (14,300 cy of tar, oily soil, and overburden, and 3,300 cy of Arsenic Remediation Zone soil).
- PAH and Arsenic Remediation Zone soil transportation, sampling, and disposal quantity = 16,000 tons (7,100 cy of tar and oily soil at 1.5 tons/cy plus 3,300 cy of Arsenic Remediation Zone soil at 1.5 tons/cy).
- Arsenic Remediation Zone soil excavation volume = 3,300 cy.
- Overlap soil unaccounted for due to small overlap area.
- Asphalt cap area is approximately 13.2 acres.
- Estimate does not include site monitoring: groundwater monitoring for the site, regulatory oversight, annual report, and five-year review. This is included in the groundwater cost estimate.

Order of Magnitude Cost Estimate

Alternative 5a

- **Power Plant Co-Burning or Other Treatment for PAH Remediation Zone Soil**
- **Stabilization of Arsenic Remediation Zone Soil**
- **Phytoremediation/Asphalt/Building Cap**

Applicable Media:
PAH Remediation Zone soil, Arsenic Remediation Zone soil, Marginal Zone Soil

Description:
Transportation and treatment of PAH Remediation Zone soil, for example at a fuel blending facility or at a power plant such as Illinois Power; stabilization/solidification of Arsenic Remediation Zone soil with a stabilizing or cementing material such as lime, fly ash, or portland cement to immobilize the contaminants; and provide vegetative cover of prairie grasses and/or trees to minimize/prohibit direct exposure, minimize infiltration by evapotranspiration, and potentially enhance bioremediation of PAHs in portions of the vadose zone.

Cost Estimate:

Item	Quantity	Units	Unit Cost	Cost
Power Plant Co-Burning: PAH Remediation Zone				
Excavation, Segregation, Debris Management	14,300	CY	$25	$358,000
Soil Processing and Loading	16,000	Ton	$40	$640,000
Sampling/Testing	16,000	Ton	$10	$160,000
Transportation	16,000	Ton	$60	$960,000
Thermal Treatment at Power Plant	16,000	Ton	$50	$800,000
Backfill and Compact Soil:				
Designated Soil Stockpile	5,000	CY	$5	$25,000
Off-Site Fill Material and Overburden Backfill	2,200	CY	$15	$33,000
Subtotal: Power Plant Co-Burning				$2,976,000
Solidification/Stabilization: Arsenic Remediation Zone				
Excavate Soil, Debris Management	3,300	CY	$25	$83,000
Stabilize/Solidify Soil	5,000	Ton	$80	$400,000
Backfill and Compact Stabilized Soil	4,000	CY	$5	$20,000
Subtotal: Solidification/Stabilization				$503,000

Phytoremediation Cover				
Subgrade Preparation	22.0	Ac.	$2,000	$44,000
Tree Planting (~200 Trees/Acre)	4,400	Ea.	$30	$132,000
Site Restoration	1	LS	$100,000	$100,000
O&M–Maintain Cap ($85,000/yr. for 30 yrs. at 5%)	1	LS	$1,310,000	$1,310,000
Subtotal: Phytoremediation Cover				$1,586,000
Itemized Total				$5,065,000
Mobilization/Demobilization, Engineering, and Administration (See Note 1)				$2,093,000
Total				$7,200,000

Note 1: Mob/Demob, Engineering and Administration is based on 50 percent of the on site work and 25 percent for the transportation and disposal.

Assumptions:

- Assumes addition of 50 percent stabilization material for Arsenic Remediation Zone soil.
- Soil density of 1.5 tons/cy.
- Thermal treatment at Illinois Power.
- PAH Remediation Zone soil will require segregation and mixing with coal.
- PAH Remediation Zone soil increases in weight by 50 percent after adding coal.
- May have difficulties with processing or stabilizing pond sediment, high PAH concentrations, and/or oily soils.
- Arsenic Remediation Zone soil expands by 20 percent after stabilizing.
- Requires maintenance and repair over the long term.
- Minimal grading for runoff.
- Excavation and segregation volume of PAH Remediation Zone soil = 14,300 cy (7,100 cy of tar & oily soil and 7,200 cy of overburden).
- Soil processing and loading weight of PAH Remediation Zone soil = 16,000 tons (7,100 cy of tar & oily soil at 1.5 tons/cy plus addition of coal).
- Arsenic Remediation Zone soil stabilization quantity = 5,000 tons (3,300 cy at 1.5 tons/cy).
- Arsenic Remediation Zone soil backfill volume = 4,000 cy (3,300 cy at 20% expansion)
- Trees would consist of either mulberry or evergreens (red cedar or ponderosa). Prairie grass would consist of little blue stem or switch grass.
- Arsenic Remediation Zone soil excavation volume = 3,300 cy.
- Overlap soil unaccounted for due to small overlap area.
- Phytoremediation cap area is approximately 22 acres.

Order of Magnitude Cost Estimate

Alternative 5b

- **Power Plant Co-Burning or Other Treatment for PAH Remediation Zone Soil**
- **Stabilization of Arsenic Remediation Zone Soil**
- **Asphalt/Building Cap**

Applicable Media:
PAH Remediation Zone soil, Arsenic Remediation Zone soil, Marginal Zone Soil

Description:
Transportation and treatment of PAH Remediation Zone soil, for example at a fuel blending facility or at a power plant such as Illinois Power; stabilization/solidification of Arsenic Remediation Zone soil with a stabilizing or cementing material such as lime, fly ash, or portland cement to immobilize the contaminants; and installing asphalt parking surface which will prohibit contact with subsurface soils and reduce infiltration through paved areas and promote runoff.

Cost Estimate:

Item	Quantity	Units	Unit Cost	Cost
Power Plant Co-Burning: PAH Remediation Zone				
Excavation, Segregation, Debris Management	14,300	CY	$25	$358,000
Soil Processing and Loading	16,000	Ton	$40	$640,000
Sampling/Testing	16,000	Ton	$10	$160,000
Transportation	16,000	Ton	$60	$960,000
Thermal Treatment at Power Plant	16,000	Ton	$50	$800,000
Backfill and Compact Soil:				
Designated Soil Stockpile	5,000	CY	$5	$25,000
Off-Site Fill Material and Overburden Backfill	2,200	CY	$15	$33,000
Subtotal: Power Plant Co-Burning				$2,976,000
Solidification/Stabilization: Arsenic Remediation Zone				
Excavate Soil, Debris Management	3,300	CY	$25	$83,000
Stabilize/Solidify Soil	5,000	Ton	$80	$400,000
Backfill and Compact Stabilized Soil	4,000	CY	$5	$20,000
Subtotal: Solidification/Stabilization				$503,000

Asphalt Cap				
HDPE Geomembrane	575,000	SF	$0.85	$489,000
Subbase	21,500	CY	$15	$323,000
Asphalt	575,000	SF	$2	$1,150,000
Site Restoration	1	LS	$100,000	$100,000
Stormwater Detention Pond	1	LS	$550,000	$550,000
O&M–Maintain Cover, ($5,000/yr. for 30 yrs. at 5%)	1	LS	$77,000	$77,000
Subtotal: Asphalt Cap				$2,689,000
Itemized Total				$6,168,000
Mobilization/Demobilization, Engineering, and Administration (See Note 1)				$2,644,000
Total				**$8,800,000**

Note 1: Mob/Demob, Engineering and Administration is based on 50 percent of the on-site work and 25 percent for the transportation and disposal.

Assumptions:
- Assumes addition of 50 percent stabilization material for Arsenic Remediation Zone soil.
- Soil density of 1.5 tons/cy.
- Thermal treatment at Illinois Power.
- PAH Remediation Zone soil will require segregation and mixing with coal.
- PAH Remediation Zone soil increases in weight by 50 percent after adding coal.
- May have difficulties with processing or stabilizing pond sediment, high PAH concentrations, and/or oily soils.
- Arsenic Remediation Zone soil expands by 20 percent after stabilizing.
- Pavement design will allow moderate traffic on the surface for parking or storage.
- Requires maintenance and repair over the long term.
- Runoff from cap area drains to stormwater detention pond.
- Excavation and segregation volume of PAH Remediation Zone soil = 14,300 cy (7,100 cy of tar & oily soil and 7,200 cy of overburden).
- Soil processing and loading quantity of PAH Remediation Zone soil = 16,000 tons (7,100 cy of tar & oily soil at 1.5 tons/cy plus addition of coal).
- Arsenic Remediation Zone soil excavation volume = 3,300 cy.
- Arsenic Remediation Zone soil stabilization quantity = 5,000 tons (3,300 cy at 1.5 tons/cy).
- Arsenic Remediation Zone soil backfill volume = 4,000 cy (3,300 cy with 20% expansion).
- Overlap soil unaccounted for due to small overlap area.
- Asphalt cap area is approximately 13.2 acres.
- Estimate does not include site monitoring: groundwater monitoring for the site, regulatory oversight, annual report, and five-year review. This is included in the groundwater cost estimate.

Order of Magnitude Cost Estimate

Alternative 5c

- **Power Plant Co-Burning or Other Treatment for PAH Remediation Zone Soil**
- **Stabilization of Arsenic Remediation Zone Soil**
- **Off-Site Disposal of Marginal Zone Soil**

Applicable Media:
PAH Remediation Zone soil, Arsenic Remediation Zone soil, Marginal Zone Soil

Description:
Transportation and treatment of PAH Remediation Zone soil, for example at a fuel blending facility or at a power plant such as Illinois Power; stabilization/solidification of Arsenic Remediation Zone soil with a stabilizing or cementing material such as lime, fly ash, or portland cement to immobilize the contaminants; and Transportation of soil to a permitted RCRA Subtitle D Landfill.

Cost Estimate:

Item	Quantity	Units	Unit Cost	Cost
Power Plant Co-Burning: PAH Remediation Zone				
Excavation, Segregation, Debris Management	14,300	CY	$25	$358,000
Soil Processing and Loading	16,000	Ton	$40	$640,000
Sampling/Testing	16,000	Ton	$10	$160,000
Transportation	16,000	Ton	$60	$960,000
Thermal Treatment at Power Plant	16,000	Ton	$50	$800,000
Backfill and Compact Soil:				
Designated Soil Stockpile	5,000	CY	$5	$25,000
Off-Site Fill Material and Overburden Backfill	2,200	CY	$15	$33,000
Subtotal: Power Plant Co-Burning				$2,976,000
Solidification/Stabilization: Arsenic Remediation Zone				
Excavate Soil, Debris Management	3,300	CY	$25	$82,500
Stabilize/Solidify Soil	5,000	Ton	$80	$400,000
Backfill and Compact Stabilized Soil	4,000	CY	$5	$20,000
Subtotal: Solidification/Stabilization				$503,000

Off-Site Disposal: Marginal Zone Soil				
Excavation, Segregation, Loading, and Debris Management	15,600	CY	$35	$546,000
Transportation	23,500	Ton	$15	$352,500
Sampling/Testing	23,500	Ton	$10	$235,000
Disposal at RCRA Subtitle D Landfill	23,500	Ton	$30	$705,000
Backfill and Compact Borrow Material	15,600	CY	$15	$234,000
Subtotal: Off-site Disposal				$2,072,500
Grand Total				$5,551,500
Mobilization/Demobilization, Engineering, and Contingencies (See Note 1)				$2,470,000
Total				$8,000,000

Note 1: Mob/Demob, Engineering and Contingencies is based on 50 percent of the on site work and 25 percent contingencies for the transportation and disposal costs.

Assumptions:
- Assumes addition of 50 percent stabilization material for Arsenic Remediation Zone soil.
- Soil density of 1.5 tons/cy.
- Thermal treatment at Illinois Power.
- PAH Remediation Zone soil will require segregation and mixing with coal.
- PAH Remediation Zone soil increases in weight by 50 percent after adding coal.
- May have difficulties with processing or stabilizing pond sediment, high PAH concentrations, and/or oily soils.
- Arsenic Remediation Zone soil expands by 20 percent after stabilizing.
- Excavation and segregation volume of PAH Remediation Zone soil = 14,300 cy (7,100 cy of tar & oily soil and 7,200 cy of overburden).
- Soil processing and loading quantity of PAH Remediation Zone soil = 16,000 tons (7,100 cy of tar & oily soil at 1.5 tons/cy plus addition of coal).
- Arsenic Remediation Zone soil excavation volume = 3,300 cy.
- Arsenic Remediation Zone soil stabilization quantity = 5,000 tons (3,300 cy at 1.5 tons/cy).
- Arsenic Remediation Zone soil backfill volume = 4,000 cy (3,300 cy with 20% expansion).
- Off-site disposal volume = 15,600 cy (26,000 cy of total PAH and Arsenic soil - 7,100 cy of PAH Remediation Zone soil - 3,300 cy of Arsenic Remediation Zone soil)

Order of Magnitude Cost Estimate

Alternative 6

- **Power Plant Co-Burning or Other Treatment for PAH Remediation Zone Soil**
- **Stabilization of Arsenic Remediation Zone Soil**
- **Bioremediation of Other PAH Soil**
- **Solidification/Stabilization of Marginal Zone Soil**

Applicable Media:
PAH Remediation Zone soil, Arsenic Remediation Zone soil, Marginal Zone Soil

Description:
Transportation and treatment of PAH Remediation Zone soil, for example at a fuel blending facility or at a power plant such as Illinois Power; stabilization/solidification of Arsenic Remediation Zone soil with a stabilizing or cementing material such as lime, fly ash, or portland cement to immobilize the contaminants; and bioremediation (ex-situ composting) of remaining Marginal Zone soil.

Cost Estimate:

Item	Quantity	Units	Unit Cost	Cost
Power Plant Co-Burning: PAH Remediation Zone				
Excavation, Segregation, Debris Management	14,300	CY	$25	$358,000
Soil Processing and Loading	16,000	Ton	$40	$640,000
Sampling/Testing	16,000	Ton	$10	$160,000
Transportation	16,000	Ton	$60	$960,000
Thermal Treatment at Power Plant	16,000	Ton	$50	$800,000
Backfill and Compact Soil:				
Designated Soil Stockpile	5,000	CY	$5	$25,000
Off-Site Fill Material and Overburden Backfill	2,200	CY	$15	$33,000
Subtotal: Power Plant Co-Burning				$2,976,000
Solidification/Stabilization: Arsenic Remediation Zone				
Excavate Soil, Debris Management	3,300	CY	$25	$82,500
Stabilize/Solidify Soil	5,000	Ton	$80	$400,000
Backfill and Compact Stabilized Soil	4,000	CY	$5	$20,000
Subtotal: Solidification/Stabilization				$503,000

Bioremediation (Ex-Situ Composting): Remaining PAH and Arsenic Material				
Excavation and Screening of Soil	24,900	CY	$30	$747,000
Chemical/Biological Treatment	24,900	CY	$120	$2,988,000
Revegetation	10	Acres	$10,000	$100,000
			Bioremediation: Subtotal	$3,835,000
Solidification/Stabilization: Remaining Arsenic Material				
Excavate Soil, Debris Management	1,100	CY	$25	$28,000
Stabilize/Solidify Soil	1,650	Ton	$60	$99,000
Backfill and Compact Stabilized Soil	1,350	CY	$5	$7,000
		Subtotal: Solidification/Stabilization		$134,000
			Subtotal:	$7,448,000
Mobilization/Demobilization, Engineering, and Contingencies (See Note 1)				$3,440,000
			Total	$10,900,000

Note 1: Mob/Demob, Engineering and Contingencies is based on 50 percent of the on site work and 25 percent contingencies for the transportation and disposal costs.

Assumptions:
- Assumes addition of 50 percent stabilization material for Arsenic Remediation Zone soil.
- Soil density of 1.5 tons/cy.
- Thermal treatment at Illinois Power.
- PAH Remediation Zone soil will require segregation and mixing with coal.
- PAH Remediation Zone soil increases in weight by 50 percent after adding coal.
- May have difficulties with processing or stabilizing pond sediment, high PAH concentrations, and/or oily soils.
- Arsenic Remediation Zone soil expands by 20 percent after stabilizing.
- Requires maintenance and repair over the long term.
- Excavation and segregation volume of PAH Remediation Zone soil = 14,300 cy (7,100 cy of tar & oily soil and 7,200 cy of overburden).
- Soil processing and loading quantity of PAH Remediation Zone soil = 16,000 tons (7,100 cy of tar & oily soil at 1.5 tons/cy plus addition of coal).
- Arsenic Remediation Zone soil excavation volume = 3,300 cy.
- Arsenic Remediation Zone soil stabilization quantity = 5,000 tons (3,300 cy at 1.5 tons/cy).
- Arsenic Remediation Zone soil backfill volume = 4,000 cy (3,300 cy with 20% expansion).
- Overlap soil unaccounted for due to small overlap area.
- PAH soil may take up to four years to treat by composting.
- Assumes PAH soil expands by 1.5 during composting.
- Bioremediation estimate includes O&M, verification sampling, material handling, and nutrients.
- Bioremediation volume = 24,900 cy (32,000 cy -7,100 cy of PAH Remediation Zone Soil)
- Bioremediation assumes revegetation of soil following completion of treatment.
- Stabilization of remaining Marginal Zone Soil volume = 1,100 cy (26,000 cy - 24,900 cy (bioremediation volume)

Order of Magnitude Cost Estimate

Alternative 7

- **Power Plant Co-Burning or Other Treatment for PAH Remediation Zone Soil**
- **Stabilization of Arsenic Remediation Zone Soil**
- **Thermal Desorption of Other PAH Soil**
- **Solidification/Stabilization of Marginal Zone Soil**

Applicable Media:
PAH Remediation Zone soil, Arsenic Remediation Zone soil, Marginal Zone Soil

Description:
Transportation and treatment of PAH Remediation Zone soil, for example at a fuel blending facility or at a power plant such as Illinois Power; stabilization/solidification of Arsenic Remediation Zone soil with a stabilizing or cementing material such as lime, fly ash, or portland cement to immobilize the contaminants; and thermal desorption of PAH soil to volatilize at high temperatures (around 1200 degrees F) and separate organic phase from soil phase for incineration in the off-gas.

Cost Estimate:

Item	Quantity	Units	Unit Cost	Cost
Power Plant Co-Burning: PAH Remediation Zone				
Excavation, Segregation, Debris Management	14,300	CY	$25	$358,000
Soil Processing and Loading	16,000	Ton	$40	$640,000
Sampling/Testing	16,000	Ton	$10	$160,000
Transportation	16,000	Ton	$60	$960,000
Thermal Treatment at Power Plant	16,000	Ton	$50	$800,000
Backfill and Compact Soil:				
Designated Soil Stockpile	5,000	CY	$5	$25,000
Off-Site Fill Material and Overburden Backfill	2,200	CY	$15	$33,000
Subtotal: Power Plant Co-Burning				$2,976,000
Solidification/Stabilization: Arsenic Remediation Zone				
Excavate Soil, Debris Management	3,300	CY	$25	$83,000
Stabilize/Solidify Soil	5,000	Ton	$80	$400,000
Backfill and Compact Stabilized Soil	4,000	CY	$5	$20,000
Subtotal: Solidification/Stabilization				$503,000

Thermal Desorption				
Excavation, Processing	24,900	CY	$80	$1,992,000
Desorber Fixed Costs	1	LS	$3,500,000	$3,500,000
Thermal Desorption of Soil	37,400	Tons	$200	$7,480,000
Backfill and Compact	24,900	CY	$5	$125,000
		Subtotal: Thermal Desorption		$13,097,000
Solidification/Stabilization: Remaining Arsenic Material				
Excavate Soil, Debris Management	1,100	CY	$25	$28,000
Stabilize/Solidify Soil	1,650	Ton	$60	$99,000
Backfill and Compact Stabilized Soil	1,350	CY	$5	$7,000
		Subtotal: Solidification/Stabilization		$134,000
			Subtotal	$16,710,000
Mobilization/Demobilization, Engineering, and Contingencies (See Note 1)				$8,080,000
			Total	$24,800,000

Assumptions:
- Assumes addition of 50 percent stabilization material for Arsenic Remediation Zone soil.
- Soil density of 1.5 tons/cy.
- Thermal treatment at Illinois Power.
- PAH Remediation Zone soil will require segregation and mixing with coal.
- PAH Remediation Zone soil increases in weight by 50 percent after adding coal.
- May have difficulties with processing or stabilizing pond sediment, high PAH concentrations, and/or oily soils.
- Thermal desorption costs include mobilization, demobilization, setup and shake down, excavation, hauling, backfilling, power, disposal of condensate, and analytical testing.
- On-site thermal desorption may require an air emissions permit.
- Thermal desorption unit cost is dependent on moisture content of the soil. Cost may increase if moisture content increases significantly.
- Arsenic concentrations do not interfere with other treatment or disposal for all but 10,000 cy of the arsenic soil.
- May have difficulties with processing or stabilizing pond sediment, high PAH concentrations, and/or oily soils.
- Arsenic soil expands by 20 percent after stabilizing.
- Excavation and segregation volume of PAH Remediation Zone soil = 14,300 cy (7,100 cy of tar & oily soil and 7,200 cy of overburden).
- Soil processing and loading quantity of PAH Remediation Zone soil = 16,000 tons (7,100 cy of tar & oily soil at 1.5 tons/cy plus addition of coal).
- Arsenic Remediation Zone soil excavation volume = 3,300 cy.
- Arsenic Remediation Zone soil stabilization quantity = 5,000 tons (3,300 cy at 1.5 tons/cy).
- Arsenic Remediation Zone soil backfill volume = 4,000 cy (3,300 cy with 20% expansion).
- Overlap soil unaccounted for due to small overlap area.
- Thermal desorption volume = 24,900 cy (32,000 cy -7,100 cy of PAH Remediation Zone Soil)
- Stabilization of remaining Marginal Zone Soil volume = 1,100 cy (26,000 cy - 24,900 cy (bioremediation volume)

Order of Magnitude Cost Estimate
Groundwater

Alternative 2

• **Monitored Natural Attenuation for Harbor and Lake**

Applicable Media:
Groundwater

Description:
Prohibition on placement of water supply wells and long-term monitoring of groundwater and surface water. Natural attenuation potentially reduces the flux of the phenols, organics, and BOD through existing natural processes, including aerobic and anaerobic biological processes as well as physical and chemical processes.

Cost Estimate:

Item	Quantity	Units	Unit Cost	Cost
Groundwater Monitoring ($80,000/year for 30 years at 5% interest)				$1,200,000
Administration, Inspection, Annual Reporting ($50,000/year for 30 years at 5% interest)				$770,000
Five-Year Review	1	LS	60,000	$60,000
Regulatory Oversight ($10,000/year for 30 years at 5% interest)				$150,000
			Subtotal	$2,200,000
Mobilization/Demobilization, Engineering, and Contingencies (50%)				$1,100,000
			Total	**$3,300,000**

Assumptions:
• Assumes monitoring 12 well nests and 4 surface water locations.
• Assumes monitoring 4 surface water sampling locations for arsenic, phenol, and ammonia quarterly.
• Assumes monitoring 12 groundwater nests for phenol, PAHs, arsenic, ammonia, BOD, COD, and BETX quarterly.

Order of Magnitude Cost Estimate

Alternative 3

- ### Infiltration Reducing Cap (Asphalt Cap) for Harbor

- ### Monitored Natural Attenuation for Lake

Applicable Media:
Groundwater

Description:
Asphalt cap on harbor side. The drainage from the cap would be collected in a surface water detention pond.

Cost Estimate:

Item	Quantity	Units	Unit Cost	Cost
Asphalt Cap				
HDPE Geomembrane	575,000	SF	$0.85	$490,000
Subbase	21,500	CY	$15	$322,500
Asphalt	575,000	SF	$2	$1,200,000
Site Restoration	1	LS	$100,000	$100,000
Retention Pond	1	LS	$550,000	$550,000
O&M–Maintain Cover, ($5,000/yr. for 30 years at 5% interest)	1	LS	$77,000	$77,000
Monitored Natural Attenuation (See Alt. 2)	1	LS	$2,200,000	$2,200,000
			Subtotal	$4,900,000
	Mobilization/Demobilization, Engineering, and Contingencies (50%)			$2,500,000
			Total	**$7,400,000**

Assumptions:
- Assumes capped area will be useable as supplementary parking for OMC and/or Waukegan Beach.
- Soil stockpile materials may be used as subgrade.
- Requires maintenance and repair over the long term.
- Asphalt cap is approximately 13.2 acres.

Order of Magnitude Cost Estimate

Alternative 3

- ## Infiltration Reducing Cap (Phytoremediation) for Harbor

- ## Monitored Natural Attenuation for Lake

Applicable Media:
Groundwater

Description:
Vegetative cover over site, consisting of prairie grasses and/or trees to minimize/prohibit direct exposure, minimize infiltration by evapotranspiration, and potentially enhance bioremediation of PAHs in portions of the vadose zone.

Cost Estimate:

Item	Quantity	Units	Unit Cost	Cost
Phytoremediation Cover				
Subgrade Preparation	22.0	AC	$2,000	$44,000
Tree Planting (~200 Trees/Acre)	4,400	EA	$30	$132,000
Site Restoration	1	LS	$100,000	$100,000
O&M–Maintain Cap ($85,000/year for 30 years at 5% interest)	1	LS	$1,300,000	$1,300,000
Monitored Natural Attenuation (See Alt. 2)	1	LS	$2,200,000	$2,200,000
Subtotal				$3,800,000
Mobilization/Demobilization, Engineering, and Contingencies (50%)				$1,900,000
			Total	**$5,700,000**

Assumptions:
- Soil stockpile materials may be used as subgrade.
- Requires maintenance and repair over the long term.
- Phytoremediation cap is approximately 22 acres.

Order of Magnitude Cost Estimate

Alternative 4

- **Vertical Barrier and Treatment Cells for Harbor and Lake**

- **Monitored Natural Attenuation for Lake**

Applicable Media:
Groundwater

Description:
Slurry wall (or other barrier) installed from till to ground surface. Extraction and reinfiltration of groundwater with movable system of wells (cells), that operate at a location for a period of time, then are moved to a new location. Extracted groundwater is treated, and reinjected at the cell. Provides treatment of arsenic, phenol, organics, and ammonia. Each cell operates at 15 gpm with four cells operating for a total of 60 gpm.

Cost Estimate:

Item	Quantity	Units	Unit Cost	Cost
Slurry Wall	3400	LF	$630	$2,100,000
Groundwater Extraction/Reinfiltration Pumps, Pipes & Controls	1	LS	$500,000	$500,000
Groundwater Treatment System @ 60 GPM				
Field Pilot Study	1	LS	$760,000	$760,000
Arsenic Treatment System	1	LS	$190,000	$190,000
Organics Treatment System	1	LS	$800,000	$800,000
Ammonia Treatment System	1	LS	$1,400,000	$1,400,000
Treatment Center & Start-Up	1	LS	$1,300,000	$1,300,000
Extraction/Reinjection Cells OM&R ($400,000/year for 5 years at 5%)				$1,800,000
Groundwater Treatment Operation and Monitoring ($660,000/year for arsenic, organics, and monitoring, $280,000/year for ammonia for 1-5 years) [1]				$8,900,000
Treatment Equipment Maintenance and Repair ($120,000/year for 1-5 years)				$680,000
Monitored Natural Attenuation (See Alt. 2)	1	LS	$2,200,000	$2,200,000
			Subtotal	$21,000,000
Mobilization/Demobilization, Engineering and Administration (50%)				$11,000,000
			Total	**$32,000,000**

Assumptions:

- Assumes the process train produces a nonhazardous sludge for disposal in a conventional (Subtitle D) landfill.
- Includes concrete pad, building for treatment equipment, and capital cost for biological and metals treatment systems.
- OM&R includes supplies, utilities, chemicals, labor, sampling and analysis, repair and maintenance for the treatment plant, and groundwater extraction/reinjection system.
- Assumes slurry wall of 3,400 LF, and 30-foot deep.

[1] The annual groundwater treatment and monitoring cost for 1 - 5 years is $940,000 (pumping from cells, 60 GPM), and for 6 - 30 years is $340,000 (maintaining pumpout system for slurry wall, approximately 1 GPM). The $8,900,000 equivalent present worth accounts for this change in annual cost.

Order of Magnitude Cost Estimate

Alternative 5

- **Infiltration Reducing Cap**

- **Treatment Cells for Harbor and Lake**

- **Monitored Natural Attenuation for Lake**

Applicable Media:
Groundwater

Description:
Extraction and reinfiltration of groundwater with movable system of wells (cells), that operate at a location for a period of time, then are moved to a new location. Extracted groundwater is treated, and reinjected at the cell. Provides treatment of arsenic, phenol, organics, and at least 40 % of the ammonia. Each cell operates at 15 gpm with 4 cells operating for a total of 60 gpm.

Cost Estimate:

Item	Quantity	Units	Unit Cost	Cost
Groundwater Extraction/Reinjection Pumps, Pipes & Controls	1	LS	$450,000	$450,000
Groundwater Treatment System @ 60 GPM				
Field Pilot Study	1	LS	$760,000	$760,000
Arsenic Treatment System	1	LS	$190,000	$190,000
Organics and Partial Ammonia Treatment System	1	LS	$1,200,000	$1,200,000
Treatment Center & Start-Up	1	LS	$890,000	$890,000
Extraction/Reinjection Cells OM&R ($400,000/year for 5 years at 5%)				$1,800,000
Groundwater Treatment Operation and Monitoring ($430,000/year for arsenic and monitoring, $280,000/year for organics and partial ammonia for 5 years at 5%)				$3,100,000
Treatment Equipment Maintenance and Repair ($78,000/year for 5 years at 5%)				$300,000
Monitored Natural Attenuation (See Alt. 2)	1	LS	$2,200,000	$2,200,000
Subtotal				$10,900,000
Mobilization/Demobilization, Engineering and Administration (50%)				$5,500,000
Total				$16,400,000

Assumptions:

- Assumes the process train produces a nonhazardous sludge for disposal in a conventional (Subtitle D) landfill.
- Includes concrete pad, building for treatment equipment, and capital cost for biological and metals treatment systems.
- OM&R includes supplies, utilities, chemicals, labor, sampling and analysis, repair and maintenance for the plant and groundwater extraction/reinfiltration system.

Order of Magnitude Cost Estimate

Alternative 6

• **Aquifer Restoration**

Applicable Media:
Groundwater

Description:
Extraction of groundwater by means of wells (vertical or horizontal) or drains, treatment of groundwater, and discharge to the POTW. Provides treatment of organics, phenol, ammonia, cyanide/thiocyanate, and metals to meet North Shore Sanitary District (NSSD) requirements. Flow rate of 200 gpm is sufficient to handle infiltration and 10 pore volumes of the affected aquifer in a timeframe of 40 to 60 years.

Cost Estimate:

Item	Quantity	Units	Unit Cost	Cost
Groundwater Extraction/Discharge Pumps, Pipes & Controls	1	LS	$1,400,000	$1,400,000
Groundwater Treatment System @ 200 GPM				
Field Pilot Study	1	LS	$1,000,000	$1,000,000
Arsenic Treatment System	1	LS	$240,000	$240,000
Organics Treatment System	1	LS	$1,300,000	$1,300,000
Ammonia Treatment System	1	LS	$3,100,000	$3,100,000
UV/Peroxide Treatment System	1	LS	$4,500,000	$4,500,000
Treatment Center & Start-Up	1	LS	$2,300,000	$2,300,000
Extraction/Discharge OM&R ($90,000/year for 50 years at 5%)				$1,600,000
Groundwater Treatment Operation and Monitoring ($1,300,000/year for arsenic, organics, monitoring, and discharge, $520,000/year for ammonia, $210,000/year for UV/Peroxide treatment for 50 years at 5%)				$36,000,000
Treatment Equipment Maintenance and Repair ($610,000/year for 50 years at 5%)				$11,000,000
Subtotal				$62,000,000
Mobilization/Demobilization, Engineering and Administration (50%)				$31,000,000
Total				**$93,000,000**

Assumptions:
• Assumes treatment of organics, phenol, ammonia, arsenic and cyanide would be required for discharge to NSSD

- Assumes the process train produces a nonhazardous sludge for disposal in a conventional (Subtitle D) landfill.
- Includes concrete pad, storage tank, building for equipment, pump station to sanitary sewer and capital cost for biological and metals treatment systems.
- O&M includes supplies, utilities, chemicals, labor, sampling and analysis, repair and maintenance for the plant and wastewater discharge to NSSD (NSSD charges at $4/1,000 gal.).
- Normal NSSD charges are $0.1/gallon; at this rate, the cost of this option increases to $370,000,000.
- Enormous quantities of groundwater (5 billion gallons) would need to be treated.

Appendix 5-A

Components of Alternatives - Vadose Zone Soil

Appendix 5-A

Components of Alternatives
Vadose Zone Soil

List of Figures

Appendix 5-A

Components of Alternatives
Vadose Zone Soil

This appendix summarizes the potential vadose zone soil remedial actions which have been retained for detailed analysis. The retained technologies include:

- Asphalt/Building Cap (Alternative 2)

- Phytoremediation Cap (Alternative 3)

- Power Plant Co-Burning (or other treatment) of PAH Remediation Zone Material (Alternative 2, 3, and 4)

- Stabilization/Solidification of Arsenic Remediation Zone Material (Alternative 2, 3, and 4)

- Onsite Containment Unit (Alternative 2)

- Disposal (Alternative 2, 3, and 4)

- Institutional Controls (Alternatives 2 and 3)

Various combinations of these technologies have been combined into comprehensive remedial alternatives for the site. The following sections provide a detailed description of the individual components, and provide action specific details for implementing these technologies.

1.0   Asphalt Cap

An asphalt parking area or buildings is considered a potential method of capping portions of the vadose zone soil to reduce infiltration through the site and to reduce the potential for direct exposure topsoil in the future. This component of potential vadose zone soil remedial actions includes existing buildings or paved surfaces which may remain, as well as the installation of new paved areas. The capped area would be approximately 12 acres.

An asphalt cap would consist of approximately 12 inches of subbase covered by 3 inches of asphalt. (A synthetic liner may be added beneath the subbase if necessary). The preliminary design of an asphalt cap is shown on Figure 5-A-1. This pavement design would permit use of the asphalt surface for moderate vehicle traffic for parking or long term storage of vehicles. The cap would be placed after the area is regraded with material from an on-site source.

The cap design would include consolidating PAH soil at the site by moving PAH-contaminated soil from near the new slip to the east part of the site. PAH soil will be covered to reduce the potential for direct exposure. To protect groundwater, soil with arsenic concentrations greater than 25 mg/kg will be covered. This material would not be consolidated due to the diffuse nature of the arsenic within the soil at the site, thus this factor controls the design area of the cap. As part of the remedial design, areas that do not have either 6 inches of clean soil or pavement to prevent direct exposure contact above 10^{-5} RHE will be determined. These areas will be covered by 6 inches of clean fill or an equivalent cap. The design objective for this cap will be to reduce infiltration by at least 90 percent. Because infiltration is significantly reduced, the volume of stormwater runoff generated at the site will increase as the capped area increases.

Due to the size of the asphalt cap, a stormwater retention pond was included in the detailed analysis. A stormwater system will serve the capped area, and will direct precipitation runoff to a lined detention pond for stormwater quality improvement prior to discharge to the harbor.

The cost for the construction of an asphalt cap and the associated stormwater detention basin is shown in detail in Appendix 5-C. It is anticipated that any asphalt surface cap would likely require maintenance and repair over the long term. These costs are also included in the cost estimate.

2.0 Phytoremediation Cap

A phytoremediation cap would provide a vegetative cover of prairie grasses and trees. Similar to other caps, a phytoremediation cap would reduce direct exposure to vadose zone soils and the reduce infiltration by increasing evapotranspiration. Phytoremediation also enhances the potential for microbial decomposition of PAHs in the rhyzosphere by increasing the availability of oxygen within the root zone and by creating organic acids which stimulate biological activity.

For Alternative 3, the entire unused area of the site would be covered with a phytoremediation cap, except those zones that require impermeable pavement cover. If areas of the phytoremediation cap are redeveloped in the future portions of this cap can be replaced by a building or asphalt cap. As with the asphalt cap, the purpose of the phytoremediation cap would be to limit direct exposure to PAHs in soil and to minimize the potential for arsenic to migrate from the soil to the groundwater.

For the detailed analysis, a phytoremediation cap is assumed to consist of either mulberry, poplars or possibly evergreen (red cedar or ponderosa) trees in combination with prairie grasses such as little blue stem or switch grass. Trees would be placed at a spacing of approximately 15 feet on center,

while the grasses would be planted uniformly across the entire area to be covered. Due to historical soil compaction of surface soils, the area to be capped would need to first be tilled or plowed to prepare the area for revegetation. Minimal additional topsoil may be added during the final regrading of the area. However, as part of the remedial design, areas that do not have 6 inches of clean soil to prevent direct exposure contact above 10^{-5} RHE will be determined. These areas will be covered by 6 inches of clean fill prior to placement of the phytoremediation cap. The area would then be planted with trees, grass and other vegetation.

The phytoremediation cap will be very effective for minimizing infiltration of precipitation. Evapotranspiration is the process by which plants and soil return moisture to the atmosphere. A well developed stand of plants at the WCP site will produce nearly the maximum evapotranspiration (called the potential evapotranspiration) because the shallow groundwater provides an unlimited supply of water. In the Chicago area, the average annual potential evapotranspiration over the last 30 years has been about 40 inches (Hasse, 1998). The average rainfall for Waukegan has been about 33 inches.

Thus, it is likely that the annual evapotranspiration from a phytoremediation cap will exceed the annual precipitation. This expectation is consistent with the Ohio water balance study reviewed in Dr. Fletcher's assessment of phytoremediation for the WCP site (Fletcher, 1998). In the Ohio study, evapotranspiration nearly equaled the total precipitation and condensation (dew) on an annual basis, even without a shallow water table.

Appendix 5-D presents hydraulic modeling results of the potential reduction in the groundwater flux from the site due to the establishment of a phytoremediation cap. Two cases are modeled in Appendix 5-D for the phytoremediation cap. One case uses a 100 percent reduction in infiltration, the expected case based on the Ohio study and hydrologic considerations. The second case uses a 50 percent reduction in infiltration, which illustrates that even with less performance than anticipated, a phytoremediation is quite effective.

The potential costs for the phytoremediation cap component are summarized in Appendix 5-C.

3.0 Power Plant Co-Burning or Other Treatment of PAH Remediation Zone Material

The PAH remediation zone is estimated to include 7,100 cubic yards of soil with the highest concentrations of PAHs at the site. For this alternative, this material would be treated or disposed of

either offsite or onsite. The treatment or disposal may be by any of a number of technologies, including co-burning, thermal desorption with disposal onsite or offsite, or in-situ thermal desorption. For the detailed analysis of this component of the potential remedial alternatives, it is assumed that the PAH zone material would be thermally treated by co-burning the material at Illinois Power's Baldwin generating station located near St. Louis, Missouri. The final specification of a treatment facility would be determined during the design phase.

The location of the PAH soil is shown on Figure 4-1. This area also contains approximately 500 cubic yards of the PAH soil that may contain high concentrations of arsenic which would need to be addressed by the selected remedy.

Soil excavated for treatment or disposal would be processed at the site concurrently with the excavation. Onsite processing would include removal of very large debris and possibly mixing the material with coal, wood ash, or some other high carbon material to improve materials-handling properties, and facilitate transportation and off-loading of the material. For detailed analysis purposes, the weight of the processed material was assumed to be 50 percent heavier than the PAH zone material. Any irregular material such as used reinforcing steel would also need to be removed during onsite processing to allow the material to be transported efficiently and disposed of offsite at a licensed disposal facility. The Baldwin facility can accept material up to 12 inches in diameter, so any debris larger than 12 inches would be removed in the field.

Under currently accepted protocols, MGP soils which may potentially exhibit hazardous characteristics for benzene or other contaminants in accordance with TCLP testing requirements are not considered hazardous wastes if onsite processing removes the hazardous characteristic. Processed material which is not hazardous by TCLP is typically removed from a site as a special waste and may be manifested for record keeping purposes prior to being co-burned or otherwise treated at an offsite location.

In 1998, the U.S. EPA promulgated additional Land Disposal Rules (LDRs) for newly listed wastes. These new rules may affect the protocol which has been used to process and/or treat MGP soils onsite, and to transport and co-burn these materials offsite. These new rules add some uncertainty to the potential implementability and cost estimates for all ex situ treatment alternatives for soil. Appendix 4-E includes correspondence from the U.S. EPA and an additional interpretive letter clarifying the Phase IV LDRs on cleanup of MGP sites. The key criteria from the EEI strategy that will be incorporated in the remedial design phase include the following:

- Soil will be processed within the area of contamination

- TCLP testing for benzene and/or arsenic as necessary will be completed prior to transporting the soil off-site

- Soil failing TCLP after processing will be managed in accordance with RCRA hazardous waste requirements.

The remedial design work will include pre-identifying areas considered likely to have soil which fails TCLP, so special management can be provided for these soils. A more detailed assessment of the potential impact of these rules will be completed during the remedial design.

Transportation of processed materials from Chicago to St. Louis would be either by truck or by barge. Generally, trucking is the least complicated transportation option. At the Baldwin facility, additional processing would include passing the material through a crusher to reduce all material to less than 2 inches in diameter as required by the facility.

Treatment of the material at the Baldwin generating station, or other thermal treatment facility would be completed in accordance with the applicable operating permits. Destruction of PAHs during co-burning would be virtually complete.

Costs for thermal treatment are included in the detailed cost estimates in Appendix 5-C.

4.0   Stabilization/Solidification of Arsenic Remediation Zone Material

In this alternative component, the arsenic soil and some of the arsenic/PAH overlap soil would be excavated, processed, stabilized, and backfilled at the site. Processing would include segregating debris or other unsuitable material from the soil prior to mixing the soil with the stabilizing or solidifying agents using a pugmill or other mixing equipment. After the soil is stabilized, it would be backfilled in the same area where it was excavated.

The volume of arsenic soil to be stabilized is estimated to be approximately 3,300 cubic yards. The location of this soil is shown on Figure 4-1.

Stabilization/solidification of arsenic soil and arsenic/PAH overlap soil would be accomplished using either a stabilizing or solidifying (cementing) material. Stabilization and solidification are both

immobilization technologies. Stabilization relies on chemical transformation mechanisms that do not result in a solid mass (e.g., lime, phosphate). Many proprietary stabilizing agents have been developed for stabilizing inorganic materials in tailings or other residual materials from mining operations. For example, at least one company manufactures a proprietary powder reagent that is activated by soil moisture or water to produce an electrokinetic ion exchange process which forms a matrix around the metal compound. In comparison, solidification relies on forming a solid mass which prohibits weathering effects and infiltration of leaching fluids (e.g., rain). Solidification is almost synonymous with cementation (e.g., Portland cement, siliceous pozzolans such as coal fly ash). Some immobilization technologies have properties of both stabilization and solidification (thermoplastic encapsulation).

The actual agent or agents used to stabilize or solidify the arsenic material would be determined during the remedial design. One of the primary factors which will affect the selection of the final solidifying or stabilizing agent will be the influence of PAHs and other organics in the soil matrix on the stabilization/solidification process. Stabilizing agents such as lime, asphalt, or organophyllic clays may be the most effective for arsenic soil with high concentrations of PAHs. Combinations of stabilizing or solidifying agents may also be considered. If multiple additives are used to stabilize the arsenic/PAH overlap soil they may be added at the same time or in sequence, depending on the characteristics of the materials. Treatability testing would be necessary during the remedial design phase to determine the optimum mixing sequence and ratios to provide the most cost-effective process for stabilizing and/or solidifying the arsenic material that will also satisfy the goal of immobilizing the PAHs for protection of groundwater.

Depending on the process selected, the material generated by stabilizing and/or solidifying the arsenic and arsenic-PAH soil may be backfilled as soil, or if solidified to a great extent, could be used as a subbase for a future parking lot or other at-grade structure.

Detailed cost estimates for solidification/stabilization of arsenic soils is included in Appendix 5-C.

5.0   Vault (Onsite Containment Unit)

In one component of Alternative 2, a portion of the vadose zone soil would be excavated and placed inside an onsite containment unit. The volume of soil to be excavated is estimated to be approximately 18,000 cubic yards. A potential high estimate of 36,500 cubic yards has also been considered. The volume of material to be placed in the containment unit includes the PNA soil from the Designated Soil Stockpile. The location of the containment unit for either of these volumes was

selected to cap core area groundwater. The footprint of the containment unit is the same for the representative and high-volume cases; additional capacity inside the containment unit for the high volume would be created by increasing the height of the containment unit.

Construction of the containment unit would begin with clearing, grubbing, and subgrade preparation. The conceptual design includes removal of approximately 30,000 cubic yards of soil that would likely be unsuitable foundation material. Approximately 7,500 cubic yards of this soil exceeds cleanup standards and will eventually be placed in the vault. The remaining material will be backfilled at the site in the contaminated soil excavation or used to construct portions of the vault. Soil from the footprint area of the containment unit that will eventually be placed in the containment unit will be staged over the top of other contaminated soil outside the containment unit footprint, after removing any uncontaminated surface soil. The temporary staging area would be covered, as needed, to prevent migration of runoff from soil and accumulation of water in the soil pile.

The containment unit will be constructed as shown on Figure 5-A-2. The containment unit consists of a liner, cover, leachate collection system and leak detection system, designed to standards for RCRA hazardous waste landfills.

The liner consists of the following components from top to bottom:

- 12 inches granular drainage material (permeability of 1×10^{-3} cm/s)
- HDPE leachate collection pipes
- 60-mil High Density Polyethylene (HDPE) membrane
- 12 inches granular drainage material (1×10^{-3} cm/s)
- HDPE leak detection pipes
- 60-mil HDPE membrane
- 3 feet compacted clay (1×10^{-7} cm/s)

The cap consists of the following components from top to bottom:

- 6 inches topsoil
- 18-inch rooting zone
- 12-inch granular drainage layer
- 60-mil LDPE membrane
- 6-inch granular drainage layer

Within the containment unit, the leachate collection system consists of a collection piping system, storage tank, manhole, pump and controls. Leachate water collected from the system would either be transported to a private wastewater treatment plant, or pretreated as necessary, and discharged to the North Shore Sanitary District (NSSD) Waukegan Sewage Treatment Plant. During construction and initial filling of the unit, leachate will likely be generated. After the containment unit is closed, annual leachate production will be collected. As shown on the attached figure, a leak detection system would be installed between the two geomembrane liner systems to allow leaks in the primary collection system to be detected.

The bottom of the containment unit can not be below the normal groundwater elevation. A minimum separation of 2 feet has been used between the bottom of the liner system and the top of the water table, placing the base of the liner at approximately elevation 585 feet above mean sea level. The height of the containment unit will vary depending on the actual volume placed in the containment unit. For the representative volume, the height of the unit will be 18 feet from the top of the liner to the top of the cap. For the high volume, the height of the containment unit would be 19 feet. The slopes of the final cover will be between 5 and 10 percent to provide adequate drainage.

The costs for the onsite containment unit are included in Appendix 5-C. Costs include both capital costs and long term costs for closure and post-closure monitoring.

6.0   Disposal

Transportation of soil to a permitted offsite RCRA Subtitle C Hazardous Waste Disposal Facility, or a Subtitle D industrial waste disposal facility is included in the development of Alternatives 2, 3, and 4. The volume of material that would be disposed varies for these alternatives from 10,400 cubic yards for Alternatives 2 and 3 up to 112,000 cubic yards for Alternative 4.

For Alternatives 2 and 3, the material to be removed would include all of the soil within the PAH remediation zone and the arsenic remediation zone. For Alternative 4 all of the arsenic remediation zone soil which would need to be capped in Alternative 2 and 3 would be removed for offsite disposal. This represents a total volume of approximately 112,000 cubic yards.

The material at the site is not a listed waste. However, portions of the material may be characteristically hazardous. It may be necessary to treat material at the site to remove any hazardous characteristics prior to disposal or to have the material treated at the facility prior to disposal.

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Transportation of the material from the site to an offsite disposal facility would most likely be by truck. Barge, or train transport alternatives could be considered during the remedial design. Material removed from the site for disposal, regardless of the disposal location, would be manifested to provide accurate records of the quantity of material removed and the final destination of the material. Numerous acceptable offsite disposal facilities are available within a limited distance of the site. For this analysis, disposal in a RCRA Subtitle C facility located in Peoria, Illinois was assumed.

Detailed costs for excavation, transportation, and offsite disposal of soil are included in Appendix 5-C.

7.0   Institutional Controls

Institutional controls for vadose zone soil for Alternative 2 and 3 include a Soil Management Plan. The purpose of the Soil Management Plan is to provide worker protection for operations in areas with remaining soil exceeding 10^{-6} RHE and to provide guidance for defining where soil institutional controls are needed. The Soil Management Plan will be developed during the remedial design and updated after the remedial action and will include a figure showing the following components:

- Designate clean utility corridors
- Designate areas where sampling is required for intrusive work
- Identify areas backfilled with clean soil

ALTERNATIVE 3B
ASPHALT CAP

3" ASPHALT
SLOPE TO DRAIN

12" AGGREGATE BASE

ALTERNATIVE 3C
PHYTOREMEDIATION CAP

CAP
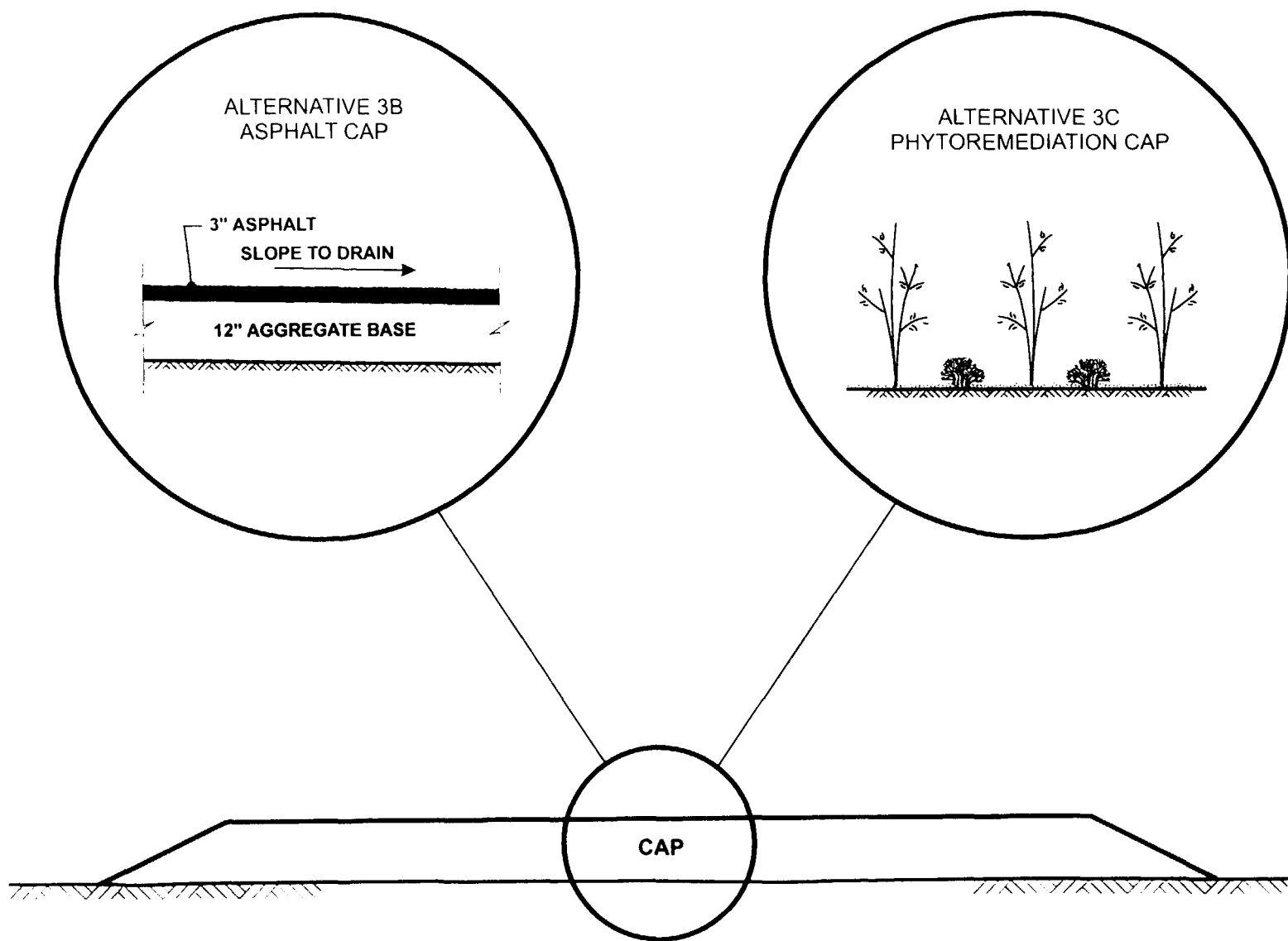
Figure 5-A-1

ATERNATIVE 2 and 3
CONTAINMENT AND REMOVAL
ASPHALT AND PHYTOREMEDIATION CAP
Waukegan Manufactured Gas & Coke Plant Site

LINER SYSTEM

12" Granular Drainage Material
12" Granular Drainage Material
36" Clay Liner
6" Subbase

60 mil HDPE Membrane
60 mil HDPE Membrane

CAP/COVER SYSTEM

60 mil LDPE Membrane

6" Topsoil
18" Rooting Zone
12" Granular Drainage Material
6" Granular Drainage Material
Waste Material

Slope Varies

Waste Material

Leachate Collection Pipe

Leak Detection Pipe

Subgrade

Anchor Trenches for Membrane

Figure 5-A-2

ALTERNATIVE 2C
CONTAINMENT
VAULT CROSS SECTION
Waukegan Manufactured Gas & Coke Plant Site

Appendix 5-B

Components of Alternatives -
Groundwater

Appendix 5-B

Components of Alternatives
Groundwater

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Memorandum from Barr Engineering Company, "Groundwater Treatment System Description," October 28, 1998

Memorandum from Barr Engineering Company, "In-situ Effects of Nitrate Re-infiltration," October 28, 1998

Appendix 5-B

Components of Alternatives
Groundwater

There are three elements to the groundwater remedies for Alternatives 2 and 3:

1. Treatment Cells
2. Treatment Processes
3. Monitored Natural Attenuation

This appendix presents technical information on each of these elements.

1.0   Treatment Cells

Treatment cells are a combination of ex-situ and in-situ groundwater remediation approaches.
Each treatment cell is limited in area and duration of operation in order to concentrate and
maximize its effect. Groundwater is extracted from the cell and treated above ground. The cleanup
of the aquifer is accelerated by reinjection of the treated water at the perimeter of the cell. The
reinjection displaces impacted groundwater, which enhances the effectiveness of extraction, and
also creates the necessary conditions for in-situ biological process to occur. After the designated
effort has been applied at a cell, the equipment used to extract and inject the groundwater is
moved to a new location (or cell) and the process is repeated. The treatment cell concept is
intended to make more efficient use of time and resources than traditional downgradient capture
systems for addressing a limited remediation area.

1.1 Conceptual Design

The conceptual design described here for the treatment cells is used in this FS for cost estimation
and remedy evaluation purposes. The design balances number of wells, size of cells, groundwater
flow rate, time to extract the water from a cell, and anticipated extraction water concentrations.
Other balances between these factors may be selected in final design, but the basic concept,
features, and operational targets for the cells will remain the same.

The conceptual layout of a typical cell is illustrated in Figure 5-B-1. A line of 10 pumping wells is bracketed between two lines each of 10 reinjection wells. The lines are 50 feet from each other, and 200 feet long. This configuration allows the cell to "sweep" the area between the reinjection and pumping wells, concentrating its effect in the 100-foot by 200-foot zone inside the cell.

A cross section of the cell is shown on Figure 5-B-1. The extraction and reinjection wells are screened in the lower portion of the aquifer, so that the reinjection process helps physically displace the groundwater plume.

1.2 Cell Operation

The modeling of the cells is based on a 15 gpm flow rate, 1.5 gpm for each extraction well and 0.75 gpm for each reinjection well. Using the site aquifer parameters, the estimated time to remove one pore volume from a cell is three months. A pilot test of the cell concept should be conducted to better characterize this value and the success of extracting the groundwater plume.

Because of the balance between extraction and reinjection rates, a cell will capture essentially all the reinjected water, assuming a neutral flowfield. Several cells may be placed side by side for full-scale remediation. The capture efficiency is maintained in such a configuration, and the proportion of water that stays "inside" the cell system is increased over independently operated cells, enhancing the overall efficiency of the cells.

1.2.1 Number of Pore Volumes Extracted at Treatment Cell

According to classic modeling, virtually the entire mass in the cell of non-retarded dissolved chemicals such as ammonia and arsenic (to a limit) will be removed by the extraction of one pore volume of groundwater from a treatment cell. However, practical considerations and field experience indicate that 100 percent removal in one pore volume is unlikely. To better reflect the difficulty of complete removal, each pore volume extracted should be expected to remove only a portion of the remaining chemical in the cell. Assuming the proportion of the remaining chemical removed with each pore volume is constant, the number of pore volumes to remove for efficient extraction can be estimated. The table below illustrates the diminishing benefit of removing additional pore volumes for 50, 60, 70, and 80 percent removal of the remaining mass with each pore volume.

	Incremental Percent Removed			
Percent Removed in First Pore Volume	50	60	70	80
Percent Removed in Second Pore Volume	25	24	21	16
Percent Removed in Third Pore Volume	12	10	6	3
Percent Removed in Fourth Pore Volume	6	4	2	1

Regardless of the actual removal efficiency, this table shows that the additional benefit from removing more than two pore volumes diminishes rapidly (exponentially), and that by four pore volumes, there is essentially no value in continuing to operate. Therefore, this analysis of extraction efficiency concludes that removal of two pore volumes is the appropriate target for cell operation. Given that the cost of operating the groundwater treatment center is essentially constant over time, cost-effectiveness as well as extraction efficiency dictate that a cell be moved after about two pore volumes.

1.2.2 Cell Termination Policy

Accounting for field conditions such as aquifer heterogeneity, a target for mass removal from a cell of 70 percent removal of non-retarded dissolved chemicals (arsenic and ammonia) within two pore volumes should be used as an attainable goal. If this target has not been achieved within four volumes, this should be taken as an indication that the chemicals are not sufficiently mobile to be extracted (or to migrate) from the cell, and the treatment cell operation at that location will be terminated.

As explained above, the planned operation of each cell is to extract two pore volumes. The extraction/injection equipment is then moved to another location to repeat the two-pore-volume operation process. The time required to extract two pore volumes from one cell is estimated at three months to two years. This range is due to uncertainties in the hydraulic conductivity estimates for the site as a whole and for the base of the sand aquifer in particular. A pilot test may allow refinement of this estimate. A one-year cell operation to flush two pore volumes at each location was assumed for cost and remediation time estimation.

1.2.3 Special Considerations For Organic Chemicals

Modeling the transport of retarded chemicals in the groundwater, such as phenol, shows them to be removed at a rate approximately inversely proportional to their retardation coefficient. Phenol

removal in two pore volumes is assumed to be 35 percent, allowing for inefficiencies in extraction. This level of removal, in concert with the reduced concentrations of the other parameters (i.e., arsenic, thiocyanate, and ammonia) creates favorable conditions for intrinsic biodegradation of phenol in the cell. Alternative 3 takes advantage of these conditions by reinjecting nitrate that can further degrade the residual phenol in the cell. Thus, cell operation will enhance in-situ degradation of contaminants by removing inhibitory conditions and augmenting factors favorable to anaerobic biodegradation of organics.

2.0   Treatment Processes

The treatment cell concept involves treatment of the extracted water prior to reinjection. The parameters that are targeted for treatment are arsenic, organics (primarily phenols, but also benzene), and ammonia. The treatment systems for both Alternatives 2 and 3 aim for high arsenic removal efficiencies. The Alternative 2 treatment system places priority on ammonia removal and denitrification in the aboveground treatment system, at the expense of in-situ phenol removal, system reliability, and system operation costs. The Alternative 3 treatment system, in contrast, places priority on phenol removal, by converting ammonia to nitrate in order to provide for in-situ phenol removal (and in-situ denitrification). The potential for in-situ phenol removal is presented in the attached Barr Engineering memorandum, "In-situ Effects of Nitrate Re-Infiltration".

2.1 Influent Water Quality

The anticipated influent water quality to the treatment system is summarized in Table 5-B-1. The influent water quality is based on representative groundwater quality samples from the treatment cell operation area. The representative groundwater is estimated to be limited to the lower 5 feet out of the 30-foot aquifer thickness. It is anticipated that the extraction system will inevitably draw water from the entire 30-foot water column, although the wells are screened at the base of the aquifer in order to encourage, insofar as possible, withdrawal from the lower portions. For comparison purposes, Table 5-B-1 shows representative deep aquifer plume concentrations as well as anticipated treatment center influent concentrations. Separate estimates are provided for harbor-side and lake-side groundwater.

The treatment systems for Alternatives 2 and 3 are described in the attached Barr Engineering memorandum, "Groundwater Treatment System Description". The memorandum shows a process flow diagram of the treatment system, and an estimated water quality at each stage of the process. This analysis estimates the effectiveness of two pore volumes treatment. For the purposes of the

two pore volume analysis, certain assumptions were made regarding the aquifer and transport behavior. The aquifer was assumed to be as represented in the groundwater model. However, transport was conservatively assumed to be less efficient than suggested by advection, retardation, and dispersion modeling. Seventy percent of the modeled removal from the cell is assumed for each pore volume. The analysis accounts for operational requirements of the treatment center, such as sulfuric acid addition for pH adjustment; it also accounts for known relationships among the chemicals being treated, such as the release of ammonia when thiocyanate is aerobically biodegraded.

2.2 Alternative 2

The treatment system for Alternative 2 is a four-stage process. The estimated system influent and effluent concentrations for the first two pore volumes are shown in Table 5-B-2. From the first pore volume influent to the second pore volume treated effluent, the organics, arsenic, thiocyanate, and ammonia are each reduced by at least 85 percent in this system . The effluent concentrations are based on literature values and experience. Actual treatment efficiencies would be determined with a pilot test. The four-stage process treatment process is complex and consequently is of lower reliability and higher cost to operate than less complex systems.

Combining the treatment center effectiveness and the extraction efficiency, an estimate of the cell mass removal can be obtained. For the Alternative 2 system, the calculated mass removals for a cell are:

- arsenic, 85 percent mass removal
- ammonia, 85 percent mass removal
- phenol, 35 percent mass removal.

The effect of reinjected nitrates on the phenol removal increases the mass removal effect by about 0.5 percent. Natural attenuation mechanisms will provide additional phenol removal over time. The treatment center and aquifer removal efficiencies would need to be examined in a pilot study. The stated removals are calculated from standard treatment center efficiencies, aquifer properties, and assuming a modest (30 percent) reduction in calculated extraction efficiency from the aquifer. The modeled values are used in analyzing the alternatives, but it is recognized that cell mass removals greater than 70 percent may not be attainable.

2.3 Alternative 3

The treatment system for Alternative 3 is a two-stage process, a more robust less complex system than for Alternative 2. The estimated system influent and effluent concentrations for the first pore volumes are shown in Tables 5-B-3 and 5-B-4. The estimated influent and discharge water quality for the Alternative 3 treatment system is shown in Table 5-B-3 for the first and second pore volume. Table 5-B-3 assumes a nominal 40 percent reduction in ammonia concentration during aboveground treatment. It also assumes the ammonia released by thiocyanate degradation is converted to nitrogen, so the total system efficiency in ammonia conversion is between 50 and 60 percent. For the second pore volume, the same mass of ammonia is converted as in the first pore volume because ammonia degradation is a function of oxygen supply and residence time, not merely influent concentration. Thus, as the result of the first pore volume treatment/reinjection, followed by the second pore volume extraction and treatment, the net ammonia reduction from initial influent to second pore volume discharge is 67 percent.

Table 5-B-4 shows the Alternative 3 treatment system influent and effluent quality assuming the treatment center produces a nominal 60 percent reduction in ammonia concentration. Including the ammonia released by thiocyanate, the total system efficiency in ammonia conversion is between 60 and 70 percent. Also note that after treatment of the second pore volume, there is essentially no ammonia in the system effluent.

The organic compounds are assumed to be retarded in these analyses, with the result that the influent concentration does not change from the first to the second pore volume. The organics are subject to in-situ biodegradation, so the full level of treatment achieved with the treatment cells will be the sum of the treatment center removal and the in-situ degradation. The attached Barr Engineering memorandum, "In-situ Effects of Nitrate Re-Infiltration," explains the benefits that may be anticipated with nitrate addition in the treatment cells. Combining the treatment center effectiveness, the extraction efficiency, and the potential benefits of nitrate reinjection, an estimate of the cell mass removal can be obtained. For the Alternative 3 system, the calculated mass removals for a cell are:

- arsenic, 85 percent mass removal
- ammonia, 55 to 85 percent mass removal
- phenol, 35 to 40 percent mass removal

The higher ammonia removal corresponds to a treatment system with a 60 percent nominal ammonia conversion efficiency, the lower corresponds to a 40 percent nominal efficiency. The actual ammonia conversation efficiency of a 2-stage treatment system could exceed the nominal 60 percent assumed here, but such efficiencies should not be relied upon until demonstrated with a pilot study. The nominal 40 percent efficiency is a standard removal efficiency that can be conservatively assumed without a pilot study. The higher end of the phenol removal range assumes more than half the reinjected nitrate is consumed removing phenol. The stated removals are calculated from standard treatment center efficiencies, aquifer properties, and assuming a modest (30 percent) reduction in calculated extraction efficiency from the aquifer. The ability to achieve these levels of removal would need to be examined in a pilot test. The modeled values are used in analyzing the alternatives, but it is recognized that cell mass removals greater than 70 percent may not be attainable.

Alternative 3 and Alternative 2 both reduce arsenic and ammonia concentrations significantly, and Alternative 3 provides the advantage of encouraging additional in-situ phenol removal.

2.4 Alternative 4

The estimated influent and effluent concentrations for the very complex, costly treatment system for Alternative 4 are shown in Table 5-B-5. That system is not described further here, as the alternative is technically impracticable.

3.0   Monitored Natural Attenuation

Following treatment cell operation, the groundwater will continue to improve by natural attenuation processes. These processes include biological and chemical degradation, as well as sorption, mixing and dispersion. The cells will have reduced the concentrations in the impacted groundwater, creating the potential for enhanced biological activity.

Although nitrate will have been reinfiltrated at concentrations that can exceed groundwater standards, it is useful to have nitrate present for both the short-term phenol removal in the cell (discussed above), and the long-term continued degradation of residual contaminants (e.g., as a fundamental part of the monitored natural attenuation portion of the remedy). An additional consideration is that, once the cap is placed on the site, the groundwater divide will move east. This will result in moving the residual nitrate deeper into the aquifer, bringing the nitrate into

contact with residual contamination (phenols) and areas of higher BOD. Both nitrate and phenols can then be consumed in anoxic denitrification.

A second form of biological activity to be expected during monitored natural attenuation is anaerobic sulfate reduction. As described in Section 2 and Appendix (2-E), the data from the 1997 beach transect sampling provides strong evidence of intrinsic bioremediation at the upper fringe of the impacted groundwater. The small vertical "transition zone" for phenol as compared to chloride and other parameters, and the absence of sulfate in the fringe where the phenol has disappeared, are complementary evidence of an anaerobic sulfate reduction (intrinsic bioremediation) of the phenols.

Monitored natural attenuation is a process that will affect the entire areal extent of the impacted groundwater. The processes operate at the upper fringe of the impacted groundwater and progressively work their way downward. A detailed examination of natural attenuation processes and timeframes for improvement is presented in Appendix 5-E. As shown in that appendix, as the inhibiting factors in the groundwater are alleviated, whether through treatment cell operation or natural processes, intrinsic bioremediation of organic compounds such as phenol can be very effective.

Monitoring of natural attenuation can be performed with a combination of existing wells and new monitoring wells. In the areas where cells have operated, the plume reduction will have been monitored and demonstrated by samples of the pumped water and treated water. Tracking of representative natural attenuation effects can be accomplished using wells in the MW-12/MW-13/MW-14 line. The addition of two more well nests at intermediate locations along that line will provide both a sentinel well system for detecting adverse changes in groundwater quality and a monitoring system to show benefits from treatment cell operations and natural attenuation. Figure 5-B-2 shows a system of sentinel wells and the treatment cell operation area.

By locating the sentinel wells toward the upgradient end of the treated area, they will be able to provide early warning of groundwater plume exceedances. Should exceedances of the target groundwater criteria occur, treatment cells could be operated to address the situation before a threat to surface water quality develops. The criteria for implementing such a follow-up action will depend on what proves feasible to achieve in the field with treatment cells.

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Table 5-B-1

Estimated Groundwater Treatment System Influent Concentrations
Waukegan Manufactured Gas and Coke Plant Site

Parameter	Lake Side Groundwater[1]		Harbor Side Groundwater[2]	
	Estimated Treatment System Influent Concentration	Representative Groundwater Quality	Estimated Treatment System Influent Concentration	Representative Groundwater Quality
Organics				
Phenols 4AAP, mg/L	112	980	42	362
Phenol, mg/L	55	470	18	150
Cresols, total, mg/L	28	240	11	94
2,4-Dimethylphenol, mg/L	1.5	13	1.2	10
Benzene, mg/L	0.098	0.87	0.15	1.3
Inorganics				
Arsenic, mg/L	4.2	37	2.1	18
Chloride, mg/L	390	3,300	330	2,800
Cyanide, mg/L	0.075	0.639	0.056	0.483
Sulfate, mg/L	58	500	20	170
Thiocyanate, mg/L	68	580	28	240
Nitrogen, ammonia as N, mg/L	126	1,100	190	1,600
General Parameters				
Nitrogen, total kjeldahl, mg/L	210	1,800	210	1,800
Biochemical Oxygen Demand, mg/L	360	3,100	180	1,500
Chemical Oxygen Demand, mg/L	620	5,300	290	2,500
Carbon, total organic, mg/L	160	1,400	98	840
Carbon, dissolved organic, mg/L	150	1,200	110	970

Notes:

1   Representative groundwater quality is the average of the deepest samples from the beach transect (SB6130, SB6230, SB6330) and monitoring wells MW4D, MW7D, and MW13D, using samples from 1996 and 1997. The estimated treatment system influent concentration is 1/6 of the representative groundwater concentration, reduced by 30 percent to allow for hydraulic inefficiencies in groundwater transport.

2   Representative harbor side groundwater concentration is the average of monitoring wells MW1D and MW6D, using samples from 1996 and 1997. The estimated treatment system influent concentration is 1/6 of the representative harbor side groundwater concentration, reduced by 30 percent to allow for hydraulic inefficiencies in groundwater transport.

Table 5-B-2

Alternative 2
Estimated Groundwater Treatment System Influent and Effluent Concentrations
Waukegan Manufactured Gas and Coke Plant Site

Parameter	Representative Concentration, Lower 5 feet of Groundwater	Pore Volume 1		Pore Volume 2	
		Treatment System Influent Concentration	Treatment System Effluent Concentration[1]	Treatment System Influent Concentration	Treatment System Effluent Concentration[1]
Organics					
Phenol 4AAP, mg/L	980	112	2	112	2
Phenol, mg/L	470	55	1	55	1
Cresols total, mg/L	240	28	0.3	28	0.3
2,4-Dimethylphenol, mg/L	13	1.54	0.05	1.54	0.05
Benzene, mg/L	0.87	0.098	0.01	0.098	0.01
Inorganics					
Arsenic, mg/L	37	4.2	0.5	1.61	0.2
Chloride, mg/L	3,300	385	385	385	385
Cyanide, mg/L	0.639	0.0749	0.4	0.30	0.2
Sulfate, mg/L	500	58.1	108	93	143
Thiocyanate, mg/L	580	67.9	16.5	32	7.8
Nitrogen, ammonia an N, mg/L	1,100	126	13.88	47	5.3
Nitrate	0	0	24.8	17	12.9
General Parameters					
Nitrogen total kjeldahl, mg/L	1,800	210	44	94	20
Biochemical Oxygen Demand (5-day), mg/L	3,100	357	30	357	30
Chemical Oxygen Demand, mg/L	5,300	616	192	616	192
Carbon, total organic, mg/L	1,400	161	72	161	72
Carbon, dissolved organic, mg/L	1,200	147	67	147	67

[1]   Treatment efficiencies are based on literature values and experience. Actual treatment efficiencies would be determined in a pilot test.

Table 5-B-3

Alternative 3
Estimated Groundwater Treatment System Influent and Effluent Concentrations
(Nominal 40 Percent Ammonia Conversion)
Waukegan Manufactured Gas and Coke Plant Site

Parameter	Representative Concentration, Lower 5 Feet of Groundwater	Pore Volume 1		Pore Volume 2	
		Treatment System Influent Concentration	Treatment System Effluent Concentration[1]	Treatment System Influent Concentration	Treatment System Effluent Concentration[1]
Organics					
Phenol 4AAP, mg/L	980	112	11.2	112	11.2
Phenol, mg/L	470	55	5.5	55	5.5
Cresols total, mg/L	240	28	2.8	28	2.8
2,4-Dimethylphenol, mg/L	13	1.54	0.15	1.54	0.15
Benzene, mg/L	0.87	0.098	0.02	0.098	0.02
Inorganics					
Arsenic, mg/L	37	4.2	0.6	1.7	0.2
Chloride, mg/L	3,300	385	385	385	385
Cyanide, mg/L	0.639	0.0749	0.6	0.44	0.4
Sulfate, mg/L	500	58.1	108	93	143
Thiocyanate, mg/L	580	67.9	18	33	9
Nitrogen, ammonia as N, mg/L	1,100	126	76	91	41
Nitrate, as N, mg/L	0	0	50	35	85
General Parameters					
Nitrogen total kjeldahl, mg/L	1,800	210	160	175	125
Biochemical Oxygen Demand (5-day), mg/L	3,100	357	10	357	10
Chemical Oxygen Demand, mg/L	5,300	616	246	616	246
Carbon, total organic, mg/L	1,400	161	64	161	64
Carbon, dissolved organic, mg/L	1,200	147	58.8	147	58.8

[1] Treatment efficiencies are based on literature values and experience. Actual treatment efficiencies would be determined in a pilot test.

Table 5-B-4

Alternative 3
Estimated Groundwater Treatment System Influent and Effluent Concentrations
(Nominal 60 Percent Ammonia Conversion)
Waukegan Manufactured Gas and Coke Plant Site

Parameter	Representative Concentration, Lower 5 Feet of Groundwater	Pore Volume 1		Pore Volume 2	
		Treatment System Influent Concentration	Treatment System Effluent Concentration[1]	Treatment System Influent Concentration	Treatment System Effluent Concentration[1]
Organics					
Phenol 4AAP, mg/L	980	112	11.2	112	11.2
Phenol, mg/L	470	55	5.5	55	5.5
Cresols total, mg/L	240	28	2.8	28	2.8
2,4-Dimethylphenol, mg/L	13	1.54	0.15	1.54	0.15
Benzene, mg/L	0.87	0.098	0.02	0.098	0.02
Inorganics					
Arsenic, mg/L	37	4.2	0.59	1.7	0.2
Chloride, mg/L	3,300	385	385	385	385
Cyanide, mg/L	0.639	0.0749	0.6	0.44	0.4
Sulfate, mg/L	500	58.1	108	93	143
Thiocyanate, mg/L	580	67.9	18	33	9
Nitrogen, ammonia as N, mg/L	1,100	126	50	73	1
Nitrate, as N, mg/L	0	0	86	60	137
General Parameters					
Nitrogen total kjeldahl, mg/L	1,800	210	134	157	85
Biochemical Oxygen Demand (5-day), mg/L	3,100	357	10	357	10
Chemical Oxygen Demand, mg/L	5,300	616	246	616	246
Carbon, total organic, mg/L	1,400	161	64	161	64
Carbon, dissolved organic, mg/L	1,200	147	58.8	147	58.8

[1]   Treatment efficiencies are based on literature values and experience. Actual treatment efficiencies would be determined in a pilot test.

Table 5-B-5

Alternative 4
Estimated Groundwater Treatment System Influent and Effluent Concentrations
Waukegan Manufactured Gas and Coke Plant Site

Parameter	Treatment System Influent Concentration	Treatment System Effluent Concentration[1]	NSSD Discharge Limits
Organics			
Phenol 4AAP, mg/L	160	0.6	4
Phenol, mg/L	78	0.2	—
Cresols total, mg/L	40	0.06	—
2,4-Dimethylphenol, mg/L	2.2	0.03	—
Benzene, mg/L	0.14	0.004	—
Inorganics			
Arsenic, mg/L	6	0.8	1
Chloride, mg/L	550	550	—
Cyanide, mg/L	0.107	0.021	0.025
Sulfate, mg/L	83	133	—
Thiocyanate, mg/L	97	0.039	—
Nitrogen, ammonia as N, mg/L	180	11.8	50
Nitrate, as N, mg/L	0	21	45
General Parameters			
Nitrogen total kjeldahl, mg/L	300	44	—
Biochemical Oxygen Demand (5-day), mg/L	510	10	300
Chemical Oxygen Demand, mg/L	880	133	900
Carbon, total organic, mg/L	230	28	—
Carbon, dissolved organic, mg/L	210	35	—

[1] Treatment efficiencies based on literature values and experience.

A

Reinfiltration Line

100'

Pumping Line

Treatment Center

Reinfiltration Line

200'

A'

⊙ Pumping Well

⊗ Reinfiltration Well

PLAN VIEW OF A CELL

Reinfiltration 0.75 gpm

Pumping 1.5 gpm

Reinfiltration 0.75 gpm

Groundwater Surface During Cell Operation (Exaggerated)

50'

50'

CROSS SECTION VIEW OF A CELL
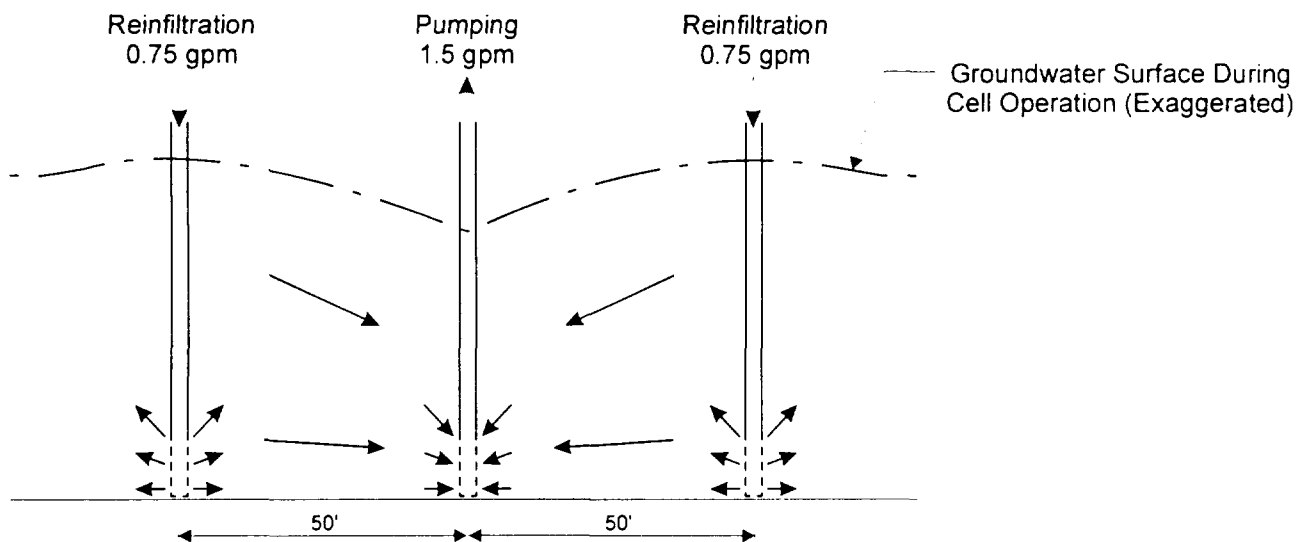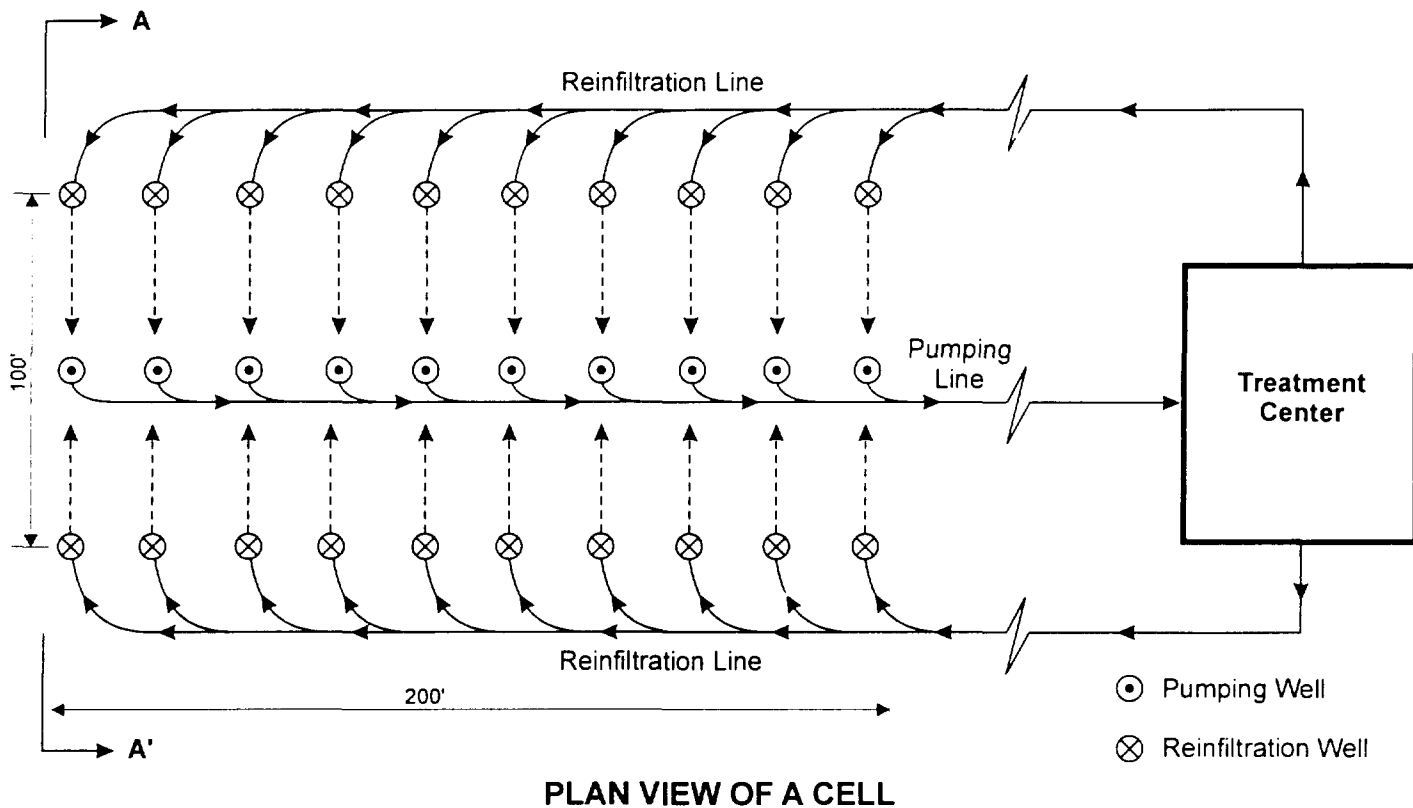
Figure 5-B-1

ALTERNATIVES 2 & 3
CONCEPTUAL LAYOUT FOR A TYPICAL CELL
Waukegan Manufactured Gas & Coke Plant Site

⊗ SW-01
<0.0014

ᕲ SW-02
<0.0014

⊙L-2
<0.002

L-3⊙
<0.002

○ SB-64

×
SB-51
0.280

○ SB-63
50.8

×
SB-52
0.890

×
SB-53
0.150

○ SB-62
62.7

PUBLIC BEACH

MW-12
-/ND/0.013/0.0221/-
-/2.60/2.00/3.01/-

○ SB-61
21

×   MW-13△   ×
-/0.032/0.031/0.157/0.143
-/27.0/20.5/29.0/23.8

-/0.090/0.060/0.079/-
-/0.760/0.630/1.10/-
△
MW-14

(Horse Drive)

10

20

MW-7 △
-/0.345/0.170/0.313/-
-/11.0/14.0/19.0/-

MW-4 △
0.018/-/0.026/0.0309/-
24.5/-/70.0/59.8/-

△MW-8
-/ND/0.003/ND/-
-/0.800/3.70/9.60/-

△   Existing Well Nest And Sample Results:
    Water Table Sample
    Base Of Aquifer Samples

×   1993 Hydropunch Boring And Sample Results:
    Base Of Aquifer Sample

○   1997 Hydropunch Boring And Sample Results:
    Base Of Aquifer Sample

⊗   Surface Water Samples And Sample Results

0   200
SCALE IN FEET

Figure 5-B-2

PROPOSED SENTINEL WELL LOCATIONS, SHOWING
ARSENIC CONCENTRATIONS IN GROUNDWATER
AND SURFACE WATER
(Concentrations In mg/L)

Barr Engineering Co.

MEMORANDUM

To: File
From: John K. Berrigan, Jr., P.E.
Subject: Groundwater Treatment System Description
Date: October 28, 1998
Project: Waukegan Manufactured Gas and Coke Plant Site
            13/49-003 JSL 426

CC: JSL   MAD
           SKV   JMS

The proposed aboveground system treats extracted groundwater for subsequent reinjection. The selected technologies in the above ground treatment system reduce arsenic, phenols and other organics, cyanide and thiocyanate, and (optionally) ammonia. Previous investigations estimate that the groundwater will have characteristics similar to those described in Figure 1 (Influent Groundwater). The proposed technology is applicable to waters with these characteristics and represents best available and demonstrated technology (BDAT) for coke production wastewaters.

Proposed technology includes sand and grit removal, electrochemical precipitation, biological treatment augmented with activated carbon treatment and optionally a nitrification biological treatment unit with an additional option for denitrification. The process schematic in Figure 1 shows the extracted groundwater flowing to the settling tank to remove any entrained sand and grit. The groundwater then flows though an electrochemical precipitation unit for arsenic removal. Following the electrochemical precipitation unit, the groundwater flows into a biotreatment unit augmented by the addition of activated carbon for organics removal, cyanide, and thiocyanate reduction. Optionally the water could be further biotreated in a nitrification unit that converts ammonia to nitrate. As an additional option to the nitrification unit, a denitrification unit would be used to convert nitrates to elemental nitrogen, if nitrate reduction is desired. Figure 1 illustrates the a two-stage treatment system with partial ammonia removal with no denitrification. Figure 2 illustrates a four-stage treatment system with ammonia removal and denitrification.

Each of these unit processes is applicable to this groundwater and their effects on the first pore volume of extracted groundwater are described as follows:

Settling Tank
The settling tank provides a means of removing soil particles from the groundwater. Entrained soil particles are incidental to the development of groundwater extraction wells. Entrained soil

particles have the potential to increase maintenance requirements of the electrochemical precipitation unit. The products of this unit process are grit free groundwater for subsequent treatment and recovered soils for disposal.

Electrochemical Precipitation

The electrochemical precipitation unit for arsenic removal is the first stage of treatment in both Figures 1 and 2. Electrochemical precipitation converts arsenic to a form amenable to precipitation though the catalytic oxidation of reduced forms of arsenic by hydrogen peroxide in the presence of iron solublized from process electrodes. Arsenic is removed by pH adjustment and coprecipitation with iron. Arsenic removal is required before biological treatment because the groundwater concentrations anticipated are likely to be toxic or inhibitory to biological treatment. As the precipitated arsenic passes between electrically charged plates within the unit, the fine precipitated arsenic is drawn out of the water stream and collected for disposal. The water leaving the unit is adjusted to pH levels appropriate for subsequent biological treatment.

Hydrogen peroxide and pH adjustment chemicals (sulfuric acid and sodium hydroxide) are required in this unit process. The products from this unit process are sludges that are subsequently dewatered for disposal, and grit-free groundwater that has a reduced arsenic content and a pH level appropriate for biological treatment.

Anticipated removal efficiencies for arsenic in this process are approximately 80% of the anticipated influent concentration. No significant removals of other constituents are expected. However, some mild degradations of thiocyanate to cyanide are expected, increasing the free cyanide concentrations in the groundwater. Adjustment of pH is expected to mildly raise the salt content (predominantly sulfate) of the water.

Biological Treatment Augmented with Activated Carbon

The second stage of treatment shown in Figures 1 and 2 is biological treatment. The biological treatment unit uses acclimated microorganisms to consume and degrade phenols and other organic compounds (as represented by BOD, COD, TOC, and DOC), cyanide and thiocyanate. The addition of activated carbon (shown in the figure as powdered activated carbon) provides further removals of organics though adsorption. The microorganisms consume and destroy the organic constituents

in the water through aerobic degradation and respiration using oxygen dissolved in the water. Blowers that supply diffused air to the treatment unit tank replenish oxygen consumed by the microorganisms. The treatment unit removes organics at a rate limited by the mass of live microorganisms, and the rate of oxygen replenishment provided by air blowers.

The microorganisms are self perpetuating in this unit. Initial or replacement cultures are available at any municipal wastewater treatment plants and especially well-acclimated cultures are available regionally from industrial wastewater plants treating coke production wastewaters. The mass of microorganisms grows as it feeds on the groundwater contaminants. Excess biomass is removed for subsequent disposal. The activated carbon provides enhanced retention of the organic constituents in the water though adsorption. Activated carbon lost though the removal of excess biomass is replenished though regular addition.

Activated carbon, and air supplied by blowers through diffusers are required in this unit process. The products from this unit process are sludges that are subsequently dewatered for disposal, and grit-free groundwater that has a reduced arsenic and organic content at roughly neutral pH levels.

Anticipated removal efficiencies for phenols are approximately 90% of the influent concentration. Anticipated removal efficiencies for the compound phenol are approximately 90% of the influent concentration. Anticipated removal efficiencies for the compound 2,4 dimethylphenol are approximately 90% of the influent concentration. Anticipated removal efficiencies for the compound benzene are approximately 80% of the influent concentration.

Anticipated additional removals of arsenic are anticipated to be approximately 30% of the biotreatment unit influent concentration, for a net removal of about 84%. Anticipated removal efficiencies for cyanide are approximately 80% of the influent concentration. Anticipated removal efficiency for thiocyanate is approximately 70% of the influent concentration.

Anticipated removal efficiency for BOD is approximately 90% of the influent concentration. Anticipated removal efficiencies for COD, TOC and DOC are approximately 60% of the influent concentration.

No significant removals of other constituents are expected. However, degradations of thiocyanate and cyanide are expected, increasing the ammonia and TKN concentrations in the groundwater.

Ammonia Removal (Optional)

The third stage of treatment in Figure 2 is a nitrification system for ammonia removal. Nitrification in general uses specific microorganisms to consume and degrade ammonia (generally expressed in mg/l as N). The microorganisms consume and convert ammonia to nitrates in the water through aerobic degradation and respiration using oxygen dissolved in the water. Blowers that supply diffused air to the treatment unit tank replenish oxygen consumed by the microorganisms. The treatment unit converts ammonia at a rate limited by the mass of live microorganisms, and the rate of oxygen replenishment provided by air blowers.

The microorganisms are self-perpetuating in this unit. Initial or replacement cultures are available at any nitrifying municipal wastewater treatment plant. The mass of microorganisms grows as it feeds on the ammonia. Excess biomass is removed for subsequent disposal.

Air supplied by blowers though diffusers is required in this unit process. The products from this unit process are sludges that are subsequently dewatered for disposal, and grit-free groundwater that has reduced arsenic, organic, and ammonia content and an elevated nitrate content at roughly neutral pH levels.

Anticipated conversion efficiencies for ammonia to nitrate are dependent upon the design of the nitrifying unit. Specific removal efficiencies and design parameters can be determined through pilot testing. However, similar treatment systems achieve significant ammonia removals in a two-stage system (Figure 1) through expansion of the second stage biotreatment unit. High conversions are possible with a three-stage stage system by adding a dedicated nitrification stage following the biotreatment (second-stage) unit.

Two-Stage Treatment

Through expansion of the second stage, the larger biotreatment unit expansion can reduce ammonia by 40%. Higher conversions may be possible with pilot testing to determine appropriate design and operating conditions. Corresponding TKN reductions are expected with ultimate level

of treatment limited to 25% of the influent TKN concentration. This analysis assumes that ammonia released by thiocyanate degradation is converted to nitrate. The total system ammonia conversion efficiency is between 50 and 60 percent in order to produce the nominal 40% reduction in influent ammonia concentrations. Nitrate levels (expressed as N) are expected to rise as a by-product of nitrification. This option is illustrated in Figure 1.

Three-Stage Treatment

The third stage of treatment, a nitrification unit (Figure 2) can reduce ammonia 90%. Corresponding TKN reductions are expected with an ultimate level of treatment limited to 80% of the influent TKN concentration. At the anticipated groundwater concentrations, first pore volume effluent levels of TKN are expected to be around 30 mg/l if an expanded dedicated nitrification system is used. Nitrate levels (expressed as N) are expected to rise to about 90 mg/l as the by-product of nitrification.

Additional removal efficiencies for phenols in the nitrification system are approximately 80% of the influent concentration, for a net removal of about 98%. Anticipated removal efficiency for the compound phenol is approximately 90% of the influent concentration, for a net removal of about 98%. Anticipated removal efficiency for 2,4 dimethylphenol is approximately 70% of the influent concentration, for a net removal of about 97%. Anticipated removal efficiency for the compound benzene is approximately 70% of the influent concentration, for a net removal of about 94%.

Additional removals for cyanide are approximately 30% of the influent concentration, for a net removal of about 84%. Anticipated removal efficiency for thiocyanate is approximately 10% of the influent concentration, for a net removal of about 73%.

Anticipated removal efficiency for BOD is approximately 80% if the influent concentration, for a net removal of about 98%. Anticipated removal efficiencies for COD, TOC and DOC are approximately 20% of the influent concentration, for a net removal of about 68%.

No significant removals of other constituents are expected.

Denitrification (Optional Fourth Stage)

The optional fourth-stage treatment unit provides conversion of nitrates to nitrogen gas using a biological process known as denitrification. This fourth stage is shown in Figure 2. The denitrification unit uses specific microorganisms to use nitrate as an oxidant source for the degradation of an added organic substrate (sugar or methanol). The microorganisms consume the organic substrate in an oxygen-starved environment (anoxic), consuming nitrates in the water to assimilate the organics. Methanol or sugar solution is injected into this closed-tank unit.

The microorganisms are self-perpetuating in this unit. Initial or replacement cultures are available at any denitrifying municipal wastewater treatment plant. As the mass of microorganisms grows, excess biomass is removed for subsequent disposal.

Methanol or sugar solution is supplied from tanks through feed pumps and are required in this unit process. The products from this unit process are sludges that are subsequently dewatered for disposal, and grit-free groundwater that has reduced arsenic, organic, ammonia, and nitrate content at roughly neutral pH levels.

Anticipated removals for nitrates are approximately 80% of the influent concentration, reducing the level to approximately 18 mg/l, assuming an expanded dedicated nitrification process is utilized.

No significant removals of other constituents are expected. However, additions of sugar or methanol are anticipated to increase the effluent COD, TOC and DOC levels by approximately 20 mg/l over the influent concentration.

Second Pore Volume Treatment

The analysis of the treatment systems on Figures 1 and 2 for the second pore volume extracted from the aquifer is shown on Figure 3 (Figure 1 treatment system) and Figure 4 (Figure 2 treatment system). The influent water quality has been adjusted to account for the hydraulic and contaminant transport modeling assumptions. Figures 3 and 4 show the modeled water quality that would be reinjected after treatment of the second pore volume.

Organic compounds are assumed to remain at a constant influent concentration for the two pore volumes, and consequently the effluent concentrations are identical for the two pore volumes.

The same mass of ammonia is converted in the second pore volume as in the first pore volume, because ammonia degradation is a function of oxygen supply and residence time, not merely influent concentration. The net effect is a reduction of ammonia concentration by 67% from the first pore volume influent to the second pore volume effluent.

A nominal 60% ammonia conversion rate in the first pore volume would result in a net 95% or greater reduction of ammonia concentration over two pore volumes. This case is shown in Tables 5 and 6. Arsenic and thiocyanate have net concentration reductions over two pore volumes of 95% and 87%, respectively.

The second pore volume analysis for the four-stage system is shown on Figure 4. Again, the organic compound concentrations in the effluent are identical to those from the first pore volume, shown on Figure 2. The net arsenic removal is effectively the same as that for the two-stage system, about 95%. Thiocyanate net removal over two pore volumes is about 88%, about the same as with the two-stage system. Ammonia net removal over two pore volumes is 95% or greater.

Conservativeness in Approach

Each technology recommended for groundwater treatment has been effectively demonstrated at the site or has been in service treating waters of similar nature successfully. Standard removal efficiencies observed in operating systems have been applied to determine estimated treatment system effluent quality. Therefore, further technology demonstrations are not necessary to determine feasibility. However, additional pilot studies can determine equipment sizing, and allow replacement of standard removal efficiencies with site-specific groundwater treatment performance data.

Figure 1
Process Flow Diagram
40% Ammonia Removal

		First Pore Volume Influent Groundwater	Settling Tank Effluent	Electro-Chemical Precipitation Effluent	Biotreatment Unit Activated Sludge /PAC Effluent
Flow	gpm	60	60	60	60
	Concentration				
Phenol, 4AAP	mg/l	112	112	112	11.2
Phenol	mg/l	55	55	55	5.5
Cresols, total	mg/l	28	28	28	2.8
2-4 Dimethyl Phenol	mg/l	1.54	1.54	1.54	0.15
Benzene	mg/l	0.098	0.098	0.098	0.02
Arsenic	mg/l	4.2	4.2	0.84	0.59
Chloride	mg/l	385	385	385	385
Cyanide	mg/l	0.075	0.075	3.1	0.6
Sulfate	mg/l	58.1	58.1	108	108
Thiocyanate	mg/l	67.9	67.9	61	18
Ammonia (as N)	mg/l	126	126	126	76
Nitrate (as N)	mg/l	0	0	0	61
TKN	mg/l	210	210	210	160
BOD (5-day)	mg/l	357	357	357	10
COD	mg/l	616	616	616	246
TOC	mg/l	161	161	161	64
DOC	mg/l	147	147	147	58.8

Figure 1
Process Flow Diagram
40% Ammonia Removal

		First Pore Volume Influent Groundwater	**Settling Tank Effluent**	**Electro-Chemical Precipitation Effluent**	**Biotreatment Unit Activated Sludge /PAC Effluent**
Flow	gpd	86400	86400	86400	86400
	Mass				
Phenol, 4AAP	lb/d	81	81	81	8
Phenol	lb/d	40	40	40	4
Cresols, total	lb/d	20	20	20	2
2-4 Dimethyl Phenol	lb/d	1.1	1.1	1.1	0.1
Benzene	lb/d	0.1	0.1	0.1	0.0
Arsenic	lb/d	3	3	0.6	0.4
Chloride	lb/d	277	277	277	277
Cyanide	lb/d	0.1	0.1	2.2	0.4
Sulfate	lb/d	42	42	78	78
Thiocyanate	lb/d	49	49	44	13
Ammonia (as N)	lb/d	91	91	91	54
Nitrate	lb/d	0	0	0	44
TKN	lb/d	151	151	151	115
BOD (5 day)	lb/d	257	257	257	7
COD	lb/d	444	444	444	178
TOC	lb/d	116	116	116	46
DOC	lb/d	106	106	106	42

Figure 2
Process Flow Diagram

Arsenic Removal | Phenols/Organics Removal | Ammonia Removal

PAC · Lime · Carbon Source (i.e. corn syrup, sugar)

Influent Groundwater 60gpm → Settling Tank → Electro-Chemical Precipitation → Activated Sludge and Powdered-Activated Carbon (PAC) → Nitrification (Aerobic) → Denitrification (Anoxic) → Reinfiltrate Effluent

Air — Air —

Solids Disposal ← Filter Press

Solids Disposal ← Filter Press ← Sludge Storage (Aerobic) ← Air

		First Pore Volume Influent Groundwater	Settling Tank Effluent	Electro-Chemical Precipitation Effluent	Biotreatment Unit Activated Sludge /PAC Effluent	Nitrification Unit Effluent	Denitrification Unit Effluent
Flow	gpm	60	60	60	60	60	60
	Concentration						
Phenol, 4AAP	mg/l	112	112	112	11.2	2	2
Phenol	mg/l	55	55	55	5.5	1	1
Cresols, total	mg/l	28	28	28	2.8	0.3	0.3
2-4 Dimethyl Phenol	mg/l	1.54	1.54	1.54	0.154	0.05	0.05
Benzene	mg/l	0.098	0.098	0.098	0.02	0.01	0.01
Arsenic	mg/l	4.2	4.2	0.84	0.6	0.5	0.5
Chloride	mg/l	385	385	385	385	385	385
Cyanide	mg/l	0.075	0.075	3.1	0.6	0.4	0.4
Sulfate	mg/l	58.1	58.1	108	108	108	108
Thiocyanate	mg/l	67.9	67.9	61	18	16	16
Ammonia (as N)	mg/l	126	126	126	138	14	14
Nitrate (as N)	mg/l	0	0	0	0	124	24.8
TKN	mg/l	210	210	210	222	44	44
BOD (5-day)	mg/l	357	357	357	10	10	30
COD	mg/l	616	616	616	246	172	192
TOC	mg/l	161	161	161	64	52	72
DOC	mg/l	147	147	147	58.8	47	67

Figure 2
Process Flow Diagram

Arsenic Removal
Phenols/Organics Removal
Ammonia Removal

PAC
Lime
Carbon Source (i.e. corn syrup, sugar)

Influent Groundwater 60gpm → Settling Tank → Electro-Chemical Precipitation → Activated Sludge and Powdered-Activated Carbon (PAC) → Nitrification (Aerobic) → Denitrification (Anoxic) → Reinfiltrate Effluent

Air

Solids Disposal ← Filter Press

Solids Disposal ← Filter Press ← Sludge Storage (Aerobic) ← Air

		First Pore Volume Influent Groundwater	Settling Tank Effluent	Electro-Chemical Precipitation Effluent	Biotreatment Unit Activated Sludge /PAC Effluent	Nitrification Unit Effluent	Denitrification Unit Effluent
Flow	gpd	86400	86400	86400	86400	86400	86400
	Loading						
Phenol, 4AAP	lb/d	81	81	81	8	1.6	1.6
Phenol	lb/d	40	40	40	4	0.4	0.4
Cresols, total	lb/d	20	20	20	2	0.2	0.2
2-4 Dimethyl Phenol	lb/d	1.1	1.1	1.1	0.1	0.0	0.0
Benzene	lb/d	0.1	0.1	0.1	0.0	0.0	0.0
Arsenic	lb/d	3	3	0.6	0.4	0.4	0.4
Chloride	lb/d	277	277	277	277	277	277
Cyanide	lb/d	0.1	0.1	2.2	0.4	0.3	0.3
Sulfate	lb/d	42	42	78	78	78	78
Thiocyanate	lb/d	49	49	44	13	12	12
Ammonia (as N)	lb/d	91	91	91	99	10	10
Nitrate	lb/d	0	0	0	0	89	18
TKN	lb/d	151	151	151	160	32	32
BOD (5-day)	lb/d	257	257	257	7	7	22
COD	lb/d	444	444	444	178	124	139
TOC	lb/d	116	116	116	46	37	52
DOC	lb/d	106	106	106	42	34	48

Figure 3
Process Flow Diagram
40% Ammonia Removal

		Second Pore Volume Influent Groundwater	Settling Tank Effluent	Electro-Chemical Precipitation Effluent	Biotreatment Unit Activated Sludge /PAC Effluent
Flow	gpm	60	60	60	60
	Concentration				
Phenol, 4AAP	mg/l	112	112	112	11.2
Phenol	mg/l	55	55	55	5.5
Cresols, total	mg/l	28	28	28	2.8
2-4 Dimethyl Phenol	mg/l	1.54	1.54	1.54	0.15
Benzene	mg/l	0.098	0.098	0.098	0.02
Arsenic	mg/l	1.7	1.7	0.34	0.2
Chloride	mg/l	385	385	385	385
Cyanide	mg/l	0.44	0.44	1.9	0.4
Sulfate	mg/l	93	93	143	143
Thiocyanate	mg/l	33	33	30	9
Ammonia (as N)	mg/l	91	91	91	41
Nitrate (as N)	mg/l	43	43	43	98
TKN	mg/l	175	175	175	125
BOD (5-day)	mg/l	357	357	357	10
COD	mg/l	616	616	616	246
TOC	mg/l	161	161	161	64
DOC	mg/l	147	147	147	58.8

Figure 3
Process Flow Diagram
40% Ammonia Removal

		Second Pore Volume Influent Groundwater	Settling Tank Effluent	Electro-Chemical Precipitation Effluent	Biotreatment Unit Activated Sludge /PAC Effluent
Flow	gpd	86400	86400	86400	86400
	Mass				
Phenol, 4AAP	lb/d	81	81	81	8
Phenol	lb/d	40	40	40	4
Cresols, total	lb/d	20	20	20	2
2-4 Dimethyl Phenol	lb/d	1.1	1.1	1.1	0.1
Benzene	lb/d	0.1	0.1	0.1	0.0
Arsenic	lb/d	1	1	0.2	0.2
Chloride	lb/d	277	277	277	277
Cyanide	lb/d	0.3	0.3	1.4	0.3
Sulfate	lb/d	67	67	103	103
Thiocyanate	lb/d	24	24	21	6
Ammonia (as N)	lb/d	66	66	66	30
Nitrate	lb/d	31	31	31	71
TKN	lb/d	126	126	126	90
BOD (5-day)	lb/d	257	257	257	7
COD	lb/d	444	444	444	178
TOC	lb/d	116	116	116	46
DOC	lb/d	106	106	106	42

Figure 4
Process Flow Diagram

		Second Pore Volume Influent Groundwater	Settling Tank Effluent	Electro-Chemical Precipitation Effluent	Biotreatment Unit Activated Sludge /PAC Effluent	Nitrification Unit Effluent	Denitrification Unit Effluent
Flow	gpd	86400	86400	86400	86400	86400	86400
	Loading						
Phenol, 4AAP	lb/d	81	81	81	8	1.6	1.6
Phenol	lb/d	40	40	40	4	0.4	0.4
Cresols, total	lb/d	20	20	20	2	0.2	0.2
2-4 Dimethyl Phenol	lb/d	1.1	1.1	1.1	0.1	0.0	0.0
Benzene	lb/d	0.1	0.1	0.1	0.0	0.0	0.0
Arsenic	lb/d	1	1	0.2	0.2	0.1	0.1
Chloride	lb/d	277	277	277	277	277	277
Cyanide	lb/d	0.2	0.2	1.2	0.2	0.2	0.2
Sulfate	lb/d	67	67	103	103	103	103
Thiocyanate	lb/d	23	23	21	6	6	6
Ammonia (as N)	lb/d	34	34	34	38	4	4
Nitrate	lb/d	12	12	12	12	46	9
TKN	lb/d	68	68	68	72	14	14
BOD (5-day)	lb/d	257	257	257	7	7	22
COD	lb/d	444	444	444	178	124	139
TOC	lb/d	116	116	116	46	37	52
DOC	lb/d	106	106	106	42	34	48

Figure 5
Process Flow Diagram
60% Ammonia Removal

		First Pore Volume Influent Groundwater	Settling Tank Effluent	Electro-Chemical Precipitation Effluent	Biotreatment Unit Activated Sludge /PAC Effluent
Flow	gpm	60	60	60	60
	Concentration				
Phenol, 4AAP	mg/l	112	112	112	11.2
Phenol	mg/l	55	55	55	5.5
Cresols, total	mg/l	28	28	28	2.8
2-4 Dimethyl Phenol	mg/l	1.54	1.54	1.54	0.15
Benzene	mg/l	0.098	0.098	0.098	0.02
Arsenic	mg/l	4.2	4.2	0.84	0.59
Chloride	mg/l	385	385	385	385
Cyanide	mg/l	0.075	0.075	3.1	0.6
Sulfate	mg/l	58.1	58.1	108	108
Thiocyanate	mg/l	67.9	67.9	61	18
Ammonia (as N)	mg/l	126	126	126	50
Nitrate (as N)	mg/l	0	0	0	86
TKN	mg/l	210	210	210	134
BOD (5-day)	mg/l	357	357	357	10
COD	mg/l	616	616	616	246
TOC	mg/l	161	161	161	64
DOC	mg/l	147	147	147	58.8

Figure 5
Process Flow Diagram
60% Ammonia Removal

Arsenic Removal

Phenols/Organics Removal

PAC

Influent Groundwater 60gpm → Settling Tank → Electro-Chemical Precipitation → Activated Sludge and Powdered-Activated Carbon (PAC)

Air

Reinfiltrate Effluent

Solids Disposal ← Filter Press

Solids Disposal ← Filter Press ← Sludge Storage (Aerobic) ← Air

Flow		First Pore Volume Influent Groundwater	Settling Tank Effluent	Electro-Chemical Precipitation Effluent	Biotreatment Unit Activated Sludge /PAC Effluent
Flow	gpd	86400	86400	86400	86400
	Mass				
Phenol, 4AAP	lb/d	81	81	81	8
Phenol	lb/d	40	40	40	4
Cresols, total	lb/d	20	20	20	2
2-4 Dimethyl Phenol	lb/d	1.1	1.1	1.1	0.1
Benzene	lb/d	0.1	0.1	0.1	0.0
Arsenic	lb/d	3	3	0.6	0.4
Chloride	lb/d	277	277	277	277
Cyanide	lb/d	0.1	0.1	2.2	0.4
Sulfate	lb/d	42	42	78	78
Thiocyanate	lb/d	49	49	44	13
Ammonia (as N)	lb/d	91	91	91	36
Nitrate	lb/d	0	0	0	62
TKN	lb/d	151	151	151	97
BOD (5-day)	lb/d	257	257	257	7
COD	lb/d	444	444	444	178
TOC	lb/d	116	116	116	46
DOC	lb/d	106	106	106	42

Figure 6
Process Flow Diagram
60% Ammonia Removal

Arsenic Removal

Phenols/Organics Removal

PAC

Influent Groundwater 60gpm → Settling Tank → Electro-Chemical Precipitation → Activated Sludge and Powdered-Activated Carbon (PAC) ← Air

Reinfiltrate Effluent

Solids Disposal ← Filter Press

Solids Disposal ← Filter Press ← Sludge Storage (Aerobic) ← Air

		Second Pore Volume Influent Groundwater	Settling Tank Effluent	Electro-Chemical Precipitation Effluent	Biotreatment Unit Activated Sludge /PAC Effluent
Flow	gpm	60	60	60	60
	Concentration				
Phenol, 4AAP	mg/l	112	112	112	11.2
Phenol	mg/l	55	55	55	5.5
Cresols, total	mg/l	28	28	28	2.8
2-4 Dimethyl Phenol	mg/l	1.54	1.54	1.54	0.15
Benzene	mg/l	0.098	0.098	0.098	0.02
Arsenic	mg/l	1.7	1.7	0.34	0.2
Chloride	mg/l	385	385	385	385
Cyanide	mg/l	0.44	0.44	1.9	0.4
Sulfate	mg/l	93	93	143	143
Thiocyanate	mg/l	33	33	30	9
Ammonia (as N)	mg/l	73	73	73	1
Nitrate (as N)	mg/l	60	60	60	137
TKN	mg/l	157	157	157	85
BOD (5-day)	mg/l	357	357	357	10
COD	mg/l	616	616	616	246
TOC	mg/l	161	161	161	64
DOC	mg/l	147	147	147	58.8

Figure 6
Process Flow Diagram
60% Ammonia Removal

Arsenic Removal

Phenols/Organics Removal

PAC

Influent Groundwater 60gpm → Settling Tank → Electro-Chemical Precipitation → Activated Sludge and Powdered-Activated Carbon (PAC)

Air → Activated Sludge and Powdered-Activated Carbon (PAC)

Reinfiltrate Effluent

Solids Disposal ← Filter Press

Solids Disposal ← Filter Press ← Sludge Storage (Aerobic) ← Air

		Second Pore Volume Influent Groundwater	Settling Tank Effluent	Electro-Chemical Precipitation Effluent	Biotreatment Unit Activated Sludge /PAC Effluent
Flow	gpd	86400	86400	86400	86400
	Mass				
Phenol, 4AAP	lb/d	81	81	81	8
Phenol	lb/d	40	40	40	4
Cresols, total	lb/d	20	20	20	2
2-4 Dimethyl Phenol	lb/d	1.1	1.1	1.1	0.1
Benzene	lb/d	0.1	0.1	0.1	0.0
Arsenic	lb/d	1	1	0.2	0.2
Chloride	lb/d	277	277	277	277
Cyanide	lb/d	0.3	0.3	1.4	0.3
Sulfate	lb/d	67	67	103	103
Thiocyanate	lb/d	24	24	21	6
Ammonia (as N)	lb/d	53	53	53	1
Nitrate	lb/d	43	43	43	99
TKN	lb/d	113	113	113	61
BOD (5-day)	lb/d	257	257	257	7
COD	lb/d	444	444	444	178
TOC	lb/d	116	116	116	46
DOC	lb/d	106	106	106	42

Barr Engineering Co.

MEMORANDUM

To: Project File
            Waukegan Manufactured Gas and Coke Plant Site
From: Mark A. Deady
Subject: In-situ Effects of Nitrate Re-Infiltration
Date: October 28, 1998

A possible treatment option for the contaminated site groundwater includes partial nitrification of the influent ammonia to nitrate and also re-aeration of the treatment system effluent prior to re-injection into the groundwater. This memorandum discusses the possible benefits for implementing this option in treatment cell operations. The current configuration of each treatment cell consists of wells that would extract contaminated groundwater and re-infiltrate treated water in an area approximately 100 feet by 200 feet with an average aquifer depth of 30 feet. The assumed extraction/re-infiltration rate is 15 gpm per treatment cell. The above-ground treatment system is expected to remove approximately 90% of the phenol and a convert a proportion of the ammonia to nitrate. This memorandum evaluates two ammonia conversion efficiencies: 40% and 60%. The assumed duration for extraction and re-infiltration for each cell area is two pore volumes of the 100 foot by 200 foot by 30 foot zone. This memorandum assumes that, over the two pore volume treatment period, 50% of the mass of phenol present in the cell would be removed and treated by the above-ground treatment system.

The mass of phenols (4AAP) remaining in the dissolved phase for an individual cell after the two pore volume extraction and re-infiltration period would be approximately 1,200 pounds (lbs). Accounting for phenol sorption to the aquifer solids, the total mass of phenols may be 4,000 lbs after the two pore volume extraction and re-infiltration period. Two possible removal mechanisms may account for additional phenol removal from the aquifer, specifically aerobic degradation and anoxic denitrification. Approximately 2.4 lbs of oxygen are needed to aerobically degrade 1.0 lb of phenol (4AAP) and approximately 0.37 lbs of phenols (4AAP) are required for complete denitrification of 1.0 lbs of nitrate-nitrogen to nitrogen gas.

Under the 40% ammonia conversion to nitrate scenario, the re-infiltrated water would contain approximately 5 mg/L of dissolved oxygen (DO) and add approximately 72 lbs of DO to the entire aquifer after two pore volumes are treated. Assuming that 70% of the nitrate-nitrogen reinfiltrated during the first pore volume flush would be extracted during the second pore volume flush, the net nitrate-nitrogen added to the entire aquifer would be 1,650 lbs. If we assume that

nutrient deficiencies or inhibition effects do not interfere with the degradation process, and only phenol degradation accounts for oxygen uptake, an additional 10 lbs of phenols (4AAP) would be removed by aerobic degradation and 100 lbs of phenol (116 mg/L) would be utilized for denitrification in the lower one-sixth of the aquifer. For the upper five-sixths of the aquifer, under the same nutrient, inhibition, and removal mechanism assumptions, approximately 50 lbs of phenol would be removed by aerobic degradation and the remaining phenol (214 lbs) would be utilized for denitrification. Since there would be an excess of nitrate in the upper zone of the aquifer, approximately 45 mg/L (650 lbs) nitrate-nitrogen would remain in this zone. This excess nitrate could be converted to nitrogen gas by an alternate carbon source such as other organic constituents, or assuming it is advected to the lower portion of the aquifer, could provide for additional phenol consumption.

For the 60% ammonia conversion to nitrate scenarios the re-infiltrated water would contain approximately 5 mg/L of dissolved oxygen (DO) and add approximately 72 lbs of DO to the entire aquifer after two pore volumes are treated. Assuming that 70% of the nitrate-nitrogen reinfiltrated during the first pore volume flush would be extracted during the second pore volume flush, the net nitrate-nitrogen added to the entire aquifer would be 2,300 lbs. If we assume that nutrient deficiencies or inhibition effects do not interfere with the degradation process, and only phenol degradation accounts for oxygen uptake, an additional 10 lbs of phenols (4AAP) would be removed by aerobic degradation and 140 lbs of phenol would be utilized for denitrification in the lower one-sixth of the aquifer. For the upper five-sixth of the aquifer, under the same nutrient, inhibition and removal mechanism assumptions, approximately 50 lbs of phenol would be removed by aerobic degradation and the remaining phenol (214 lbs) would be utilized for denitrification. Since there would be an excess of nitrate in the upper zone of the aquifer, approximately 90 mg/L (1,300 lbs) nitrate-nitrogen would remain in this zone. This excess nitrate could be converted to nitrogen gas by an alternate carbon source such as other organic constituents, or assuming it is advected to the lower portion of the aquifer, it could provide for additional phenol consumption.

The above discussion assumes that the oxygen injected into the sand aquifer is used only to aerobically degrade the phenols and that phenol would be the preferred carbon source in the groundwater for denitrification. It also assumes that aerobic and denitrifying organisms are present and the conditions are favorable for growth of the population in the subsurface. The

removal rates for the two biological removal mechanisms (aerobic degradation and anoxic denitrification) discussed are relatively rapid and should be completed in the treatment cells during the extraction/re-infiltration period, possibly requiring an additional short period of time as the groundwater moves toward the harbor or the lake. Other removal mechanisms such as phenol utilization as part of anaerobic sulfate reduction or phenol degradation by other anaerobic processes may also occur in the aquifer concurrently with denitrification or after denitrification is complete.

Appendix 5-C

Detailed Cost Estimates and Assumptions

Appendix 5-C

Detailed Cost Estimates and Assumptions

List of Tables

Detailed Cost Estimate for Alternative 4

Detailed High Cost Estimate for Alternative 2

Detailed High Cost Estimate for Alternative 3

1.0 Overview

The following paragraphs describe the general approach that was used and assumptions that were made to prepare cost estimates for the remedial action alternatives that are evaluated in this Feasibility Study.

One of the nine NCP evaluation criteria that must be considered is cost. EPA guidance requires that cost estimates include consideration of capital costs and annual operation, maintenance, and repair costs. These two cost components are to be combined in an estimate of the net present worth for each remedial alternative, so that all alternatives can be compared on the basis of a single figure. That single figure represents the amount of money which, if invested in the base year and disbursed as needed, would be sufficient to cover all costs associated with the remedial alternative over its assumed life. EPA has determined that the cost estimates that are developed at the feasibility study phase should provide an accuracy of +50 percent to -30 percent. This means that the actual cost of the remedial action, when implemented, should not be more than 50 percent above the estimated amount and not more than 30 percent below the estimated amount. EPA guidance also suggests that a "sensitivity analysis" should be performed for factors that can significantly change the overall cost with only small changes in the value of the factor. This is especially true if there are important cost factors that have a high degree of uncertainty associated with them (USEPA, October 1988).

1.1 Items and Unit Costs

The cost estimates were based on the conceptual design which was developed for each alternative. Various tasks and quantities associated with the tasks were estimated using these conceptual designs. Tasks associated with each alternative were categorized under the general headings of Remediation Contractor Capital Costs, Non-Contractor Capital Costs, and Operation, Maintenance and Repair Costs. Sub-headings were included in each table to further divide the work included in these conceptual estimates, as necessary. Tables 5-C-5 through 5-C-31 include the detailed representative cost estimates for Alternatives 2 through 4. Tables 5-C-32 through 5-C-52 include the detailed high cost estimates for Alternatives 2 and 3 for the sensitivity analysis. The lists of potential tasks or capital expenditures are not considered complete, as it is not possible to identify every work item in this phase of the analysis. The lists are, however, considered satisfactory for cost estimating purposes. Unit prices for each individual task of work item were obtained from various sources including:

- Means Site Work Cost Data;
- conversations with remediation vendors;
- contractor bids on similar projects; and
- engineering experience with similar projects.

1.2 Subtotal Multipliers

Mobilization, contingencies, and engineering fees were applied to the capital costs for remediation systems as a percent of the subtotal estimated cost. Contingencies, which represent costs for items not detailed in these estimates, were applied to the operation and maintenance costs for the remediation systems as a percent of the subtotal estimated cost. Contingencies were applied to the site monitoring cost as percent of the subtotal estimated cost.

1.3 Present Worth Analysis

Present worth was calculated for all tasks that included long-term operation and maintenance, or monitoring. U.S. EPA guidance documents for cost estimating for feasibility studies (U.S. EPA, 1985; U.S. EPA, 1988) recommend using a maximum of 30 years for present worth determinations. The value of any work completed more than 30 years into the future is considered insignificant within the accuracy of these estimates compared to the costs incurred in the first 30 years. An interest rate of 5 percent was used to return future operation, maintenance, and monitoring costs to a present worth. This interest rate is recommended by the U.S. EPA (U.S. EPA, 1988).

2.0 Assumptions

The assumptions incorporated into all cost estimates are summarized on Table 5-C-1. The assumptions incorporated into a specific alternative are summarized on Table 5-C-2 through Table 5-C-4.

3.0 Detailed Cost Estimates

The detailed representative cost estimate for each alternative and respective options are summarized on Table 5-C-5 through Table 5-C-31. Tables 5-C-32 through 5-C-52 include the detailed high cost estimates for Alternatives 2 and 3 for the sensitivity analysis. The costs calculated from these tables were used to calculate the total costs summarized on Table 5-2 through Table 5-7 in the main body of this report.

4.0 Sensitivity Analysis

As discussed previously a sensitivity analysis should be performed for factors that can significantly change the overall cost. A sensitivity analysis is included for Alternatives 2 and 3. For both alternatives, the high cost for the vadose zone soil included an increase in the volume of soil excavated and treated or disposed. The volume of soil used for the representative and high cost is shown in Table 5-C-1. For both alternatives, the high cost for the groundwater included an increase in the duration of operation of treatment cells. The duration of treatment cell operation is shown in Tables 5-C-2 and 5-C-3. Tables 5-C-32 through 5-C-52 include the detailed high cost estimates for Alternatives 2 and 3.

Table 5-C-1

Common Data and Assumptions for Detailed Analysis Cost Estimates
Waukegan Manufactured Gas and Coke Plant Site

Line	Physical Properties		Value	Source	Comments
1	In-place PAH Remediation Zone Soil	High Volume	14,900 cubic yards	Barr Estimate	Assumes that limits of excavation are expanded from representative volume.
		Representative Volume	7,100 cubic yards	Barr Estimate	Based on field observations during investigation.
2	In-place Marginal Zone Soil	High Volume	90,000 cubic yards	Barr Estimate	Based on area covered by 25 mg/kg Arsenic concentration contour.
		Representative Volume	90,000 cubic yards	Barr Estimate	
3	In-place Arsenic Remediation Zone Soil	High Volume	7,200 cubic yards	Barr Estimate	Based on expanded area from representative volume.
		Representative Volume	3,300 cubic yards	Barr Estimate	Based on area covered by 900 mg/kg concentration contour.
4	Total In-place Vadose Zone Soil Volume	High Volume	112,100 cubic yards	Barr Estimate	[1] + [2] + [3] (High Volume)
		Representative Volume	100,400 cubic yards	Barr Estimate	[1] + [2] + [3] (Representative Volume)
5	Designated Soil Stockpile Volume		5,000 CY	Barr Estimate	Calculated based on topographical map of site.
6	Overburden Thickness		6 inches	Barr Estimate	Based on test trench and soil boring logs.
7	In-Place Soil Density		1.5 tons/cubic yard	Barr Estimate	Assumed based on representative density for sand and gravel.
8	Volume Expansion Factor for Excavation		1.20	Barr Estimate	Excavation expansion factor assumed by Barr.
9	Existing asphalt area		65,100 SF	Barr Estimate	Includes OMC Parking Lot and a portion of the OMC Driveway south of the site.
10	Existing asphalt thickness		6 inches	Barr Estimate	From boring logs
11	Expansion factor for loading asphalt		1.5	Barr Estimate	Expansion factor assumed by Barr.
12	Asphalt Restoration Area		26,100 SF	Barr Estimate	OMC driveway south of site.
13	Coal Mixing Ratio		50% by wt.	Barr Estimate	Estimated based on previous processing of coal tar material.
14	Debris fraction of excavated material		10% by wt.	Barr Estimate	Estimate based on test trench logs.
15	Arsenic Stabilization Expansion Factor		20% by vol.	Barr Estimate	Dependent on reagent used.
16	Water for treatment during soil remedy	High Volume	2,800,000 gallons	Barr Estimate	Includes decontamination water, contaminated area runoff, and construction dewatering.
		Representative Volume	770,000 gallons	Barr Estimate	

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Table 5-C-1 (continued)

Common Data and Assumptions for Detailed Analysis Cost Estimates
Waukegan Manufactured Gas and Coke Plant Site

Line	Physical Properties	Value	Source	Comments
COST ANALYSIS FACTORS				
17	Present Worth Project Duration	30 years	Barr Estimate	Typical postclosure period.
18	Present Worth Net Discount Rate	5%	Barr Estimate	Based on EPA RI/FS guidance (USEPA, October 1988).
19	Insurance Multiplier	0.02	MEANS Construction Cost Data, 1993	Multiplier applied to get insurance cost. Assumes high risk project, but does not include pollution liability insurance.
20	Total Bond Multiplier (Performance and Payment)	0.03	Barr Estimate	Sum of performance bond and payment bond to get total bond cost.
21	Contingency Multiplier	0.15	Barr Estimate	Multiplier applied to total itemized costs to obtain contingency costs. Contingency is for detail not itemized in order of magnitude cost estimate.

Table 5-C-2

Assumptions for Cost Estimate - Alternative 2: Containment
Waukegan Manufactured Gas and Coke Plant Site

Line	Physical Properties		Value	Source	Comments
1	Construction Duration	High Volume	7 months	Barr Estimate	Includes clearing, grubbing, excavation of contaminated soil, construction of containment unit, placement of material in unit and site restoration.
		Representative Volume	6 months	Barr Estimate	
2	On-site Containment Unit Size	High Volume	400 ft. x 550 ft.	Barr Estimate	Used as a portion of the infiltration reducing cap.
		Representative Volume	400 ft. x 550 ft.	Barr Estimate	
3	On-site Containment Unit Height	High Volume	24 ft.	Barr Estimate.	Based on conceptual design.
		Representative Volume	19 ft.	Barr Estimate	
4	On-site Containment Unit	Cap Thickness	3 ft.	Barr Estimate.	Includes topsoil, rooting zone soil and granular drainage material
		Liner Thickness	3 ft.	Barr Estimate.	Compacted clay
5	Asphalt cap area		11.9 acres	Barr Estimate	Based on 25 mg/kg arsenic concentration for soil to groundwater pathway.
6	Asphalt cap subbase thickness		12 inches	Barr Estimate	Based on conceptual design.
7	Containment Unit Area		5.0 acres	Barr Estimate	Based on soil volume.
8	Stormwater detention pond size		3.5 acres	Barr Estimate	NURP Pond design.
9	Total Capped Area		15.4 acres	Barr Estimate	Includes asphalt cap and stormwater detention pond (Alternative 2A and 2B)
10	Site restoration area		8 acres	Barr Estimate	Remaining portion of site without cap.
11	Maximum Open excavation area		205,500 SF	Barr Estimate	Used to calculate volume of water for pretreatment and disposal.

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Table 5-C-2 (cont.)

Assumptions for Cost Estimate - Alternative 2: Containment
Waukegan Manufactured Gas and Coke Plant Site

Line	Physical Properties		Value	Source	Comments
12	On-site Containment Unit Design Volume	High Volume	36,500 CY	Barr Estimate	Allows for soil expansion and debris.
		Representative Volume	18,000 CY	Barr Estimate	
Groundwater					
13	Duration of Project	Pilot Study	6 months	Barr Estimate	Test groundwater extraction and treatment system.
		Active Groundwater Remediation (Representative Cost)	5 years	Barr Estimate	Based on removal and treatment of a minimum of 2 pore volumes. Includes 20 treatment cells, 4 cells operating each year.
		Active Groundwater Remediation (High Cost)	10 years	Barr Estimate	Based on removal and treatment of a minimum of 2 pore volumes. Includes 20 treatment cells, 4 cells operating for 2 years.
		Maintenance of inward gradient and monitoring	≥ 30 years	EPA	Maximum time recommended by EPA (U.S. EPA, 1985; U.S. EPA, 1988)
14	Slurry Wall	Length	3,400 lf	Barr Estimate	Based on area of asphalt cap.
		Depth	30 ft	Barr Estimate	Depth of groundwater.
15	Groundwater extraction rate		60 gpm	Barr Estimate	4 treatment cells at 15 gpm each.

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Table 5-C-2 (cont.)

**Assumptions for Cost Estimate - Alternative 2: Containment
Waukegan Manufactured Gas and Coke Plant Site**

Line	Physical Properties		Value	Source	Comments
16	Anticipated First Pore Volume Treatment Efficiencies	Arsenic	85% removal	Barr Estimate	Removal based on average influent concentration.
		Cyanide	84% removal	Barr Estimate	Removal based on average influent concentration.
		Thiocyanate	73% removal	Barr Estimate	Removal based on average influent concentration.
		Phenol	98% removal	Barr Estimate	Removal based on average influent concentration.
		BOD (5 day)	98% removal	Barr Estimate	Removal based on average influent concentration.
		Ammonia	90% removal	Barr Estimate	Removal based on average influent concentration.
17	Reinject treated effluent to groundwater		60 gpm	Barr Estimate	Reinject at treatment cell perimeter.

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Table 5-C-3

Assumptions for Cost Estimate - Alternative 3: Removal
Waukegan Manufactured Gas and Coke Plant Site

Line	Physical Properties		Value	Source	Comments
1	Construction Duration	High Volume	7 months	Barr Estimate	Includes clearing, grubbing, excavation of contaminated soil, construction of cap, groundwater treatment system construction, and site restoration.
		Representative Volume	6 months	Barr Estimate	
2	Phytoremediation cap area		22 acres	Barr Estimate	Covers entire site to reduce infiltration.
3	Tree density (Planted 15' O.C.)		200 / acre	Barr Estimate	Based on recommendation by Dr. John Fletcher.
4	Oily zone area		6 acres	Barr Estimate	Based on conceptual design.
5	Moderately contaminated zone area		8 acres	Barr Estimate	Based on conceptual design.
6	Low contaminated zone area		8 acres	Barr Estimate	Based on conceptual design.
7	Grass plug density (Planted 1' O.C.)		43,560 / acre	Barr Estimate	Based on conceptual design.
8	Organic matter		50 CY/acre	Barr Estimate	Used to establish tree growth.
Groundwater					
9	Duration of Project	Pilot Study	6 months	Barr Estimate	Test groundwater extraction and treatment system.
		Active Groundwater Remediation (Representative Cost)	5 years	Barr Estimate	Based on removal and treatment of a minimum of 2 pore volumes. Includes 20 treatment cells, 4 cells operating each year.
		Active Groundwater Remediation (High Cost)	10 years	Barr Estimate	Based on removal and treatment of a minimum of 2 pore volumes. Includes 20 treatment cells, 4 cells operating for 2 years.
		Monitored Natural Attenuation	30 years	Barr Estimate	12 well nests and 4 surface water sampling locations, sampled quarterly.

Table 5-C-3 (cont.)

**Assumptions for Cost Estimate - Alternative 3: Removal
Waukegan Manufactured Gas and Coke Plant Site**

Line	Physical Properties		Value	Source	Comments
10	Groundwater extraction rate		60 gpm	Barr Estimate	4 cells at 15 gpm each.
11	Anticipated First Pore Volume Treatment Efficiencies	Arsenic	85% removal	Barr Estimate	Removal based on average influent concentration.
		Cyanide	80% removal	Barr Estimate	Removal based on average influent concentration.
		Thiocyanate	70% removal	Barr Estimate	Removal based on average influent concentration.
		Phenol	90% removal	Barr Estimate	Removal based on average influent concentration.
		BOD (5 day)	90% removal	Barr Estimate	Removal based on average influent concentration.
		Ammonia	40%-60% nominal removal	Barr Estimate	Removal based on average influent concentration.
12	Reinject treated effluent to groundwater		60 gpm	Barr Estimate	Reinject at treatment cell perimeter.

Table 5-C-4

Assumptions for Cost Estimate - Alternative 4: Removal of Vadose Zone Soil and Aquifer Restoration
Waukegan Manufactured Gas and Coke Plant Site

Line	Physical Properties		Value	Source	Comments
1	Construction Duration		10 months	Barr Estimate	Includes clearing, grubbing, excavation of contaminated soil, construction of groundwater treatment system, and site restoration.
2	Excavation Area		15 acres	Barr Estimate	Based on PAH and Arsenic Remediation Zones.
3	Site Restoration Area		22 acres	Barr Estimate	Restore entire site.
4	Maximum Open Excavation Area		468,000 SF	Barr Estimate	Used to calculate volume of water for pretreatment and disposal.
Groundwater					
5	Duration of Project	Pilot Study	6 months	Barr Estimate	Test groundwater extraction and treatment system.
		Active Groundwater Remediation	50 yrs	EPA	Maximum time recommended by EPA (U.S. EPA, 1985; U.S. EPA, 1988).
6	Groundwater extraction rate		200 gpm	Barr Estimate	40 wells at 5 gpm each.
7	Discharge Requirements	Arsenic	1 mg/L	NSSD Discharge Standards	NSSD Ordinance, February 1, 1995
		Cyanide	0.025 mg/L	NSSD Discharge Standards	NSSD Ordinance, February 1, 1995
		Phenol	—	NSSD Discharge Standards	NSSD Ordinance, February 1, 1995
		BOD (5 day)	300 mg/L	NSSD Discharge Standards	NSSD Ordinance, February 1, 1995
		Ammonia as N	50 mg/L	NSSD Discharge Standards	NSSD Ordinance, February 1, 1995

Table 5-C-5
Waukegan Manufactured Gas & Coke Plant Site
Remediation Contractor Capital Costs
Cost Estimate Details

Alternative 2: Containment
Vadose Zone Soil
Option 2A: Treatment
Representative Volume

ITEM	ESTIMATED QUANTITY	UNIT	UNIT DIRECT COST [1]	ITEM TOTAL DIRECT COST	SOURCE	COMMENTS
GENERAL REQUIREMENTS						
Submittals	1	LS	$20,000	$20,000	BARR	Includes contractor preparation of submittals which include work plans, QA plans, drawings, etc
Office	6	MO	$900	$5,400	MEANS	Rental of 2 - 50' x 12' trailer w/ AC
Mobilization	1	LS	$531,500	$531,500	BARR	10% of construction costs, does not include disposal
Demobilization and Decontamination	1	LS	$265,750	$265,750	BARR	5% of construction costs, does not inclued disposal
Utilities	6	MO	$600	$3,600	BARR	Estimate for FAX, telephone, toilets, heat, electricity, water, trash
Potable Water	6	MO	$800	$4,800	BARR	Includes delivered bottled water at 150 ga/week and rental of two coolers
SUBTOTAL GENERAL REQUIREMENTS:				$831,000		
SITE WORK						
Connect Utilities	1	LS	$5,000	$5,000	BARR	Includes connection of telephone and electricity to offices
Runon/runoff Control	1	LS	$10,000	$10,000	BARR	Install berms, silt fence, drainage ditches
Clear, Grub, and Subgrade Preparation	13.2	AC	$4,500.00	$59,421	MEANS	Clear & Grub brush, including stumps
Dust Control	6	MO	$4,000	$24,000	BARR	Labor and equipment for 2 hrs/day
Ambient Air Monitoring	6	MO	$15,000	$90,000	BARR	Estimate for monitoring from 3 sampling stations for metals, VOCs, particulates
Vehicle Decontamination Pad	6	LS	$4,000	$24,000	BARR	Construct a lined treatment decon area.
Vehicle Decontamination	6	MO	$5,000	$30,000	BARR	Cost for steam cleaning and operator for decon of all vehicles and equipment leaving the site
Personal Decontamination	6	MO	$1,900	$11,400	HAZCON	18'x24' trailer with negative air and 4 showers. Includes transportation
Water Storage Tanks	6	MO	$5,000	$30,000	BARR	Assume 2 Baker tanks
Access Improvements, Relocate Fence	1	LS	$10,000	$10,000	BARR	Site Improvements
SUBTOTAL SITE WORK:				$294,000		
EXCAVATION, TREATMENT, DISPOSAL, AND BACKFILL						
PAH REMEDIATION ZONE						
Set Up Processing and Stockpile Area	1	LS	$100,000	$100,000	BARR	Concrete pad for soil processing equipment, asphalt pad, concrete walls for soil staging
Strip and Stockpile Overburden	10,700	CY	$3	$32,100	BARR	Assume 6" Overburden Across Site
Remove Existing Asphalt	7,200	SY	$5	$36,000	MEANS	OMC Driveway (South of Site)
Asphalt Disposal	1,800	CY	$30	$54,000	BARR	Recycle
Excavate Soil, Separate PAH Material, and Segregate Debris	14,300	CY	$20	$286,000	BARR	7,100 CY of tar & oily soil, 7,200 cy of overburden
Soil Mixing and Loading	16,000	Ton	$40	$640,000	BARR	Screening to segregate debris and mixing with coal (50% by wt) and other on-site soil to render non-hazardous
Sampling and Testing Processed Material	16,000	Ton	$10	$160,000	BARR	TCLP analysis
Load and Haul Processed Material to Power Plant	16,000	Ton	$60	$960,000	KIPIN	Illinois Power, Baldwin power plant near East St. Louis
Thermal Treatment	16,000	Ton	$50	$800,000	KIPIN	
Clean Debris	2,100	Ton	$20	$42,000	BARR	Debris consists of bricks, rebar, concerete,timber, and pipe; assume 10% debris by weigh
Load and Haul Debris to Local Landfill	2,100	Ton	$10	$21,000	BARR	
Debris Disposal at Landfill	2,100	Ton	$20	$42,000	BARR	
Dewatering, Pre-Treatment, and Disposal of Water During Excavation	770	1,000 Gal	$400	$308,000	BARR	Treatment through treatment system ($0.30/gal), discharge to POTW ($0.10/gal)
ARSENIC REMEDIATON ZONE						
Excavate Soil and Segregate Debris	3,300	CY	$20	$66,000	BARR	
Soil Stabilization and Stockpiling	5,000	Ton	$80	$400,000	BARR	
Sampling and Testing Processed Material	5,000	Ton	$10	$50,000	BARR	TCLP analysis
BACKFILL						
Backfill and Compact Stabilized Material	4,000	CY	$15	$60,000	BARR	
Load, Haul, Backfill, and Compact Soil from Designated Stockpile and Overburder	12,200	CY	$5	$61,000	BARR	
Backfill from Off-Site Source	2,100	CY	$12	$25,200	BARR	Includes $10/cy for material and delivery to site and $2/cy for installation
SUBTOTAL EXCAVATION, TREATMENT, DISPOSAL, AND BACKFILL:				$4,143,000		

Table 5-C-5 (continued)
Waukegan Manufactured Gas & Coke Plant Site
Remediation Contractor Capital Costs
Cost Estimate Details

Alternative 2: Containment
Vadose Zone Soil
Option 2A: Treatment
Representative Volume

ITEM	ESTIMATED QUANTITY	UNIT	UNIT DIRECT COST [1]	ITEM TOTAL DIRECT COST	SOURCE	COMMENTS
ASPHALT CAPPING						
CAP CONSTRUCTION						
Import Fill for Grading/Shaping	21,300	CY	$12	$255,600	BARR	One foot cover over cap area
Aggregate Subbase	21,300	CY	$15	$319,500	BARR	12" Thick
Prepare and Roll Subbase	63,900	SY	$1	$63,900	MEANS	
Asphalt Wear Course	63,900	SY	$8	$511,200	MEANS	3" Thick
Asphalt Berm Curb	3,900	LF	$2	$7,800	MEANS	
MISCELLANEOUS						
Re-align Storm Sewer	500	LF	$70	$35,000	BARR	Includes restoration of lawn, parking lot, and manholes
De-watering/Pre-treatment, Disposal of Water During						
Storm Sewer Work	1	LS	$20,000	$20,000	BARR	Treatment through treatment system ($0.30/gal), discharge to POTW ($0.10/gal)
Abandon Monitoring Wells	4	EA	$3,000	$12,000	BARR	MW-9S,D: MW-7S,D
SUBTOTAL ASPHALT CAPPING:				$1,225,000		
STORMWATER DETENTION POND AND APPURTENANCES						
Catch Basins	6	EA	$2,000	$12,000	BARR	1 Catch Basin/2 acres of cap
Piping Between Catch Basins	2,000	LF	$50	$100,000	BARR	
Manholes	2	EA	$2,500	$5,000	BARR	
Excavation	24,000	CY	$10	$240,000	BARR	
HDPE Liner	152,500	SF	$0.85	$129,625	BARR	
Backfill	2,800	CY	$5	$14,000	BARR	On-site material
Outlet Structure	1	EA	$10,000	$10,000	BARR	
Outlet Pipe	150	LF	$75	$11,250	BARR	Outlet to harbor
SUBTOTAL STORMWATER DETENTION POND AND APPURTENANCES:				$522,000		
SITE RESTORATION						
Restore Asphalt						OMC Driveway (South of Site)
Aggregate Subbase	970	CY	$15	$14,600	BARR	
Prepare and Roll Subbase	2,900	SY	$1	$2,900	MEANS	
Asphalt Wear Course	2,900	SY	$8	$23,200	MEANS	
Misc. Grading, Establish Drainage,						
Re-spread Topsoil	1	LS	$10,000	$10,000	BARR	
Turf Establisment, Temporary Erosion Control	8	AC	$5,000	$40,000	BARR	
SUBTOTAL SITE RESTORATION:				$91,000		
ESTIMATED TOTAL FIELD COST				$7,106,000		
ESTIMATED TOTAL FIELD COST, EXCLUDING DISPOSAL				$6,306,000		
Bonds (3%)				$189,000		Does not include Disposal Costs for PAH Remediation Zone material.
Insurance (2%)				$126,000		Does not include Disposal Costs for PAH Remediation Zone material.
Contingencies (15%)				$1,066,000 [2]		
ESTIMATED TOTAL CONTRACTOR CONSTRUCTION COST:				$8,487,000		

NOTES:
[1] Unit direct cost includes labor, materials, equipment, overhead, and profit.
[2] Calculated as Contingency Multiplier times Estimated Total Field Cost

Table 5-C-6
Waukegan Manufactured Gas & Coke Plant Site
Non-Contractor Capital Costs
Cost Estimate Details

Alternative 2: Containment
Vadose Zone Soil
Option 2A: Treatment
Representative Volume

ITEM	ESTIMATED QUANTITY	UNIT	UNIT DIRECT COST [1]	ITEM TOTAL DIRECT COST		SOURCE	COMMENTS
Remedial Design Investigation							
Arsenic Stabilization Treatability Study	1	LS	$30,000	$30,000		BARR	
Soil TCLP Analyses	1	LS	$5,000	$5,000		BARR	
Regulatory Oversight	6	MO	$22,500	$135,000		BARR	
Design	1	LS	$325,000	$325,000		BARR	Includes Work Plan, Design, Construction QAPP, Remedial Action Plan, PHASP, and meetings
Permits/Permitting Assistance	1	LS	$100,000	$100,000			
Engineering Services During Remedial Action	6	MO	$15,000	$90,000		BARR	Includes meetings, design scope changes, etc
Construction Documentation							
Field engineering/construction observation	6	MO	$25,000	$150,000		BARR	Includes monitoring daily field activities during construction
Construction documentation report	1	LS	$55,000	$55,000		BARR	Final report - Includes data, statistical clean-up verification analysis, post-remedy soil management plan
Material testing	1	LS	$126,000	$126,000		BARR	2% of construction costs
SUBTOTAL NON-CONTRACTOR COSTS					$1,016,000		
CONTINGENCY (15%)					$152,000 [2]		
ESTIMATED TOTAL NON-CONTRACTOR CAPITAL COST:					$1,170,000		

NOTES:
[1] Unit price includes labor, materials, and equipment
[2] Calculated as Contingency Multiplier times Subtotal Non-Contractor Direct Costs

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Table 5-C-7
Waukegan Manufactured Gas & Coke Plant Site
Operation, Maintenance, and Repair Costs
Cost Estimate Details

Alternative 2: Containment
Vadose Zone Soil
Option 2A: Treatment
Representative Volume

ITEM	ESTIMATED QUANTITY	UNIT	UNIT DIRECT COST [1]	ANNUAL ITEM TOTAL DIRECT COST	FUTURE ITEM TOTAL DIRECT COST	YEAR FUTURE COST OCCURS	PRESENT WORTH OF DIRECT COST[2]	EQUIVALENT ANNUAL COST[2]	SOURCE	COMMENTS
Administration, Inspection, Annual Report	1	LS	$15,000	$15,000			$231,000	$15,000	BARR	
Analysis Review (every 5 years)	1	LS	$11,000			2002	$31,000	$2,000	BARR	
Regulatory Oversight	1	LS	$11,000	$11,000			$169,000	$11,000	BARR	
Maintain Final Cover	1	LS	$2,500	$2,500			$38,000	$3,000	BARR	
SUBTOTAL OM&R COSTS							$469,000	$31,000		
CONTINGENCY (15%)							$70,000	$5,000 [3]		
ESTIMATED TOTAL OPERATION, MAINTENANCE, AND REPAIR COST							$539,000	$36,000		

NOTES
[1] Unit price includes labor, materials, and equipment
[2] Present Worth values based on a net discout rate of 5% over 30 years
[3] Calculated as Contingency Multiplier times Subtotal Non-Contractor Direct Costs

Table 5-C-8
Waukegan Manufactured Gas & Coke Plant Site
Remediation Contractor Capital Costs
Cost Estimate Details

Alternative 2: Containment
Vadose Zone Soil
Option 2B: Disposal
Representative Volume

ITEM	ESTIMATED QUANTITY	UNIT	UNIT DIRECT COST [1]	ITEM TOTAL DIRECT COST		SOURCE	COMMENTS
GENERAL REQUIREMENTS							
Submittals	1	LS	$20,000	$20,000		BARR	Includes contractor preparation of submittals which include work plans, QA plans, drawings, etc
Office	6	MO	$900	$5,400		MEANS	Rental of 2 - 50' x 12' trailer w/ AC
Mobilization	1	LS	$460,800	$460,800		BARR	10% of construction costs, does not include disposal
Demobilization and Decontamination	1	LS	$230,400	$230,400		BARR	5% of construction costs, does not inclued disposal
Utilities	6	MO	$600	$3,600		BARR	Estimate for FAX, telephone, toilets, heat, electricity, water, trash
Potable Water	6	MO	$800	$4,800		BARR	Includes delivered bottled water at 150 ga/week and rental of two coolers
SUBTOTAL GENERAL REQUIREMENTS:					$725,000		
SITE WORK							
Connect Utilities	1	LS	$5,000	$5,000		BARR	Includes connection of telephone and electricity to offices
Runon/runoff Control	1	LS	$10,000	$10,000		BARR	Install berms, silt fence, drainage ditches
Clear, Grub, and Subgrade Preparation	13.2	AC	$4,500.00	$59,421		MEANS	Clear & Grub brush, including stumps
Dust Control	6	MO	$4,000	$24,000		BARR	Labor and equipment for 2 hrs/day
Ambient Air Monitoring	6	MO	$15,000	$90,000		BARR	Estimate for monitoring from 3 sampling stations for metals, VOCs, particulates
Vehicle Decontamination Pad	1	LS	$4,000	$4,000		BARR	Construct a lined treatment decon area.
Vehicle Decontamination	6	MO	$5,000	$30,000		BARR	Cost for steam cleaning and operator for decon of all vehicles and equipment leaving the site
Personal Decontamination	6	MO	$1,900	$11,400		HAZCON	18'x24' trailer with negative air and 4 showers. Includes transportation
Water Storage Tanks	6	MO	$5,000	$30,000		BARR	Assume 2 Baker tanks
Access Improvements, Relocate Fence	1	LS	$10,000	$10,000		BARR	Site Improvements
SUBTOTAL SITE WORK:					$274,000		
EXCAVATION, DISPOSAL, AND BACKFILL							
PAH REMEDIATION ZONE							
Strip and Stockpile Overburden	10,700	CY	$3	$32,100		BARR	Assume 6" Overburden Across Site
Remove Existing Asphalt	7,200	SY	$5	$36,000		MEANS	OMC Driveway (South of Site)
Asphalt Disposal	1,800	CY	$30	$54,000		BARR	Recycle, Includes transportation and disposal
Excavate Soil, Separate PAH Material	14,300	CY	$20	$286,000		BARR	7,100 CY of tar & oily soil, 7,200 cy of overburden
Soil Mixing and Loading	11,000	Ton	$40	$440,000		BARR	Mix tar with oily soil to allow for handling, loading, and unloading
Sampling and Testing	11,000	Ton	$10	$110,000		BARR	
Load and Haul PAH Material	11,000	Ton	$33	$363,000		PDC	
Disposal at RCRA Subtitle C Landfill	11,000	Ton	$75	$825,000		PDC	Disposal in Peoria, IL
Dewatering, Pre-Treatment, and Disposal of Water During Excavation	770	1,000 Gal	$400	$308,000		BARR	Treatment through treatment system ($0.30/gal), discharge to POTW ($0.10/gal)
ARSENIC REMEDIATON ZONE							
Set Up Segregation Area and Equipment	1	LS	$100,000	$100,000		BARR	Concrete pad for soil processing equipment, asphalt pad, concrete walls for staging
Excavate Soil and Segregate Debris	3,300	CY	$20	$66,000		BARR	
Sampling and Testing	5,000	Ton	$10	$50,000		BARR	
Load and Haul Arsenic Material	5,000	Ton	$33	$165,000		PDC	
Disposal at RCRA Subtitle C Landfill	5,000	Ton	$100	$500,000		PDC	Includes stabilization of Arsenic and disposal in Peoria, IL
Clean Debris	500	Ton	$20	$10,000		BARR	Debris consists of bricks, rebar, concerete,timber, and pipe; assume 10% debris by weigh
Load and Haul Debris to Local Landfill	500	Ton	$10	$5,000		BARR	
Debris Disposal at Landfill	500	Ton	$20	$10,000		BARR	
BACKFILL							
Load, Haul, Backfill, and Compact Soil from Designated Stockpile and Overburden	12,200	CY	$5	$61,000		BARR	
Backfill from Off-Site Source	5,400	CY	$12	$64,800		BARR	Includes $10/cy for material and delivery to site and $2/cy for installation
SUBTOTAL EXCAVATION, TREATMENT, DISPOSAL, AND BACKFILL:					$3,486,000		

Table 5-C-8 (continued)
Waukegan Manufactured Gas & Coke Plant Site
Remediation Contractor Capital Costs
Cost Estimate Details

Alternative 2: Containment
Vadose Zone Soll
Option 2B: Disposal
Representative Volume

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ITEM	ESTIMATED QUANTITY	UNIT	UNIT DIRECT COST [1]	ITEM TOTAL DIRECT COST	SOURCE	COMMENTS
ASPHALT CAPPING						
CAP CONSTRUCTION						
Import Fill for Grading/Shaping	21,300	SF	$12	$255,600	BARR	One foot cover over cap area
Aggregate Subbase	21,300	CY	$15	$319,500	BARR	12" Thick
Prepare and Roll Subbase	63,900	SY	$1	$63,900	MEANS	
Asphalt Wear Course	63,900	SY	$8	$511,200	MEANS	3" Thick
Asphalt Berm Curb	3,900	LF	$2	$7,800	MEANS	
MISCELLANEOUS						
Re-align Storm Sewer	500	LF	$70	$35,000	BARR	Includes restoration of lawn, parking lot, and manholes
De-watering/Pre-treatment. Disposal of Water During						
Storm Sewer Work	1	LS	$20,000	$20,000	BARR	
Abandon Monitoring Wells	4	EA	$3,000	$12,000	BARR	MW-9S,D: MW-7S,D
SUBTOTAL ASPHALT CAPPING:				$1,225,000		
STORMWATER DETENTION POND AND APPURTENANCES						
Catch Basins	6	EA	$2,000	$12,000	BARR	1 Catch Basin/2 acres of cap
Piping Between Catch Basins	2,000	LF	$50	$100,000	BARR	
Manholes	2	EA	$2,500	$5,000	BARR	
Excavation	24,000	CY	$10	$240,000	BARR	
HDPE Liner	152,500	SF	$0.85	$129,625	BARR	
Backfill	2,800	CY	$5	$14,000	BARR	On-site material
Outlet Structure	1	EA	$10,000	$10,000	BARR	
Outlet Pipe	150	LF	$75	$11,250	BARR	Outlet to harbor
SUBTOTAL STORMWATER DETENTION POND AND APPURTENANCES:				$522,000		
SITE RESTORATION						
Restore Asphalt						OMC Driveway (South of Site)
Aggregate Subbase	970	CY	$15	$14,600	BARR	
Prepare and Roll Subbase	2,900	SY	$1	$2,900	MEANS	
Asphalt Wear Course	2,900	SY	$8	$23,200	MEANS	
Misc. Grading, Establish Drainage,						
Re-spread Topsoil	1	LS	$10,000	$10,000	BARR	
Turf Establisment, Temporary Erosion Control	8	AC	$5,000	$40,000	BARR	
SUBTOTAL SITE RESTORATION:				$91,000		
ESTIMATED TOTAL FIELD COST				$6,323,000		
ESTIMATED TOTAL FIELD COST, EXCLUDING DISPOSAL				$4,998,000		
Bonds (3%)				$150,000		Does not include Disposal Costs for PAH Remediation Zone material.
Insurance (2%)				$100,000		Does not include Disposal Costs for PAH Remediation Zone material.
Contingencies (15%)				$948,000 [2]		
ESTIMATED TOTAL CONTRACTOR CONSTRUCTION COST:				$7,521,000		

NOTES:
[1] Unit direct cost includes labor, materials, equipment, overhead, and profit.
[2] Calculated as Contingency Multiplier times Estimated Total Field Cos

Table 5-C-9
Waukegan Manufactured Gas & Coke Plant Site
Non-Contractor Capital Costs
Cost Estimate Details

Alternative 2: Containment
Vadose Zone Soil
Option 2B: Disposal
Representative Volume

ITEM	ESTIMATED QUANTITY	UNIT	UNIT DIRECT COST [1]	ITEM TOTAL DIRECT COST		SOURCE	COMMENTS
Remedial Design Investigation							
Soil TCLP Analyses	1	LS	$5,000	$5,000		BARR	
Regulatory Oversight	6	MO	$22,500	$135,000		BARR	
Design	1	LS	$325,000	$325,000		BARR	Includes Work Plan, Design, Construction QAPP, Remedial Action Plan, PHASP, and meetings
Permits/Permitting Assistance	1	LS	$100,000	$100,000			
Engineering Services During Remedial Action	6	MO	$15,000	$90,000		BARR	Includes meetings, design scope changes, etc
Construction Documentation							
Field engineering/construction observation	6	MO	$25,000	$150,000		BARR	Includes monitoring daily field activities during construction
Construction documentation report	1	LS	$55,000	$55,000		BARR	Final report - Includes data, statistical clean-up verification analysis, post-remedy soil management plan
Material testing	1	LS	$100,000	$100,000		BARR	2% of construction costs
SUBTOTAL NON-CONTRACTOR COSTS					$960,000		
CONTINGENCY (15%)					$144,000 [2]		
ESTIMATED TOTAL NON-CONTRACTOR CAPITAL COST:					$1,100,000		

NOTES:
[1] Unit price includes labor, materials, and equipment
[2] Calculated as Contingency Multiplier times Subtotal Non-Contractor Direct Costs

Table 5-C-10
Waukegan Manufactured Gas & Coke Plant Site
Operation, Maintenance, and Repair Costs
Cost Estimate Details

Alternative 2: Containment
Vadose Zone Soil
Option 2B: Disposal
Representative Volume

ITEM	ESTIMATED QUANTITY	UNIT	UNIT DIRECT COST [1]	ANNUAL ITEM TOTAL DIRECT COST	FUTURE ITEM TOTAL DIRECT COST	YEAR FUTURE COST OCCURS	PRESENT WORTH OF DIRECT COST [2]	EQUIVALENT ANNUAL COST [2]	SOURCE	COMMENTS
Administration, Inspection, Annual Report	1	LS	$15,000	$15,000			$231,000	$15,000	BARR	
Analysis Review (every 5 years)	1	LS	$11,000			2002	$31,000	$2,000	BARR	
Regulatory Oversight	1	LS	$11,000	$11,000			$169,000	$11,000	BARR	
Maintain Final Cover	1	LS	$2,500	$2,500			$38,000	$3,000	BARR	
SUBTOTAL OM&R COSTS							$469,000	$31,000		
CONTINGENCY (15%)							$70,000	$5,000 [3]		
ESTIMATED TOTAL OPERATION, MAINTENANCE, AND REPAIR COST							$539,000	$36,000		

NOTES
[1] Unit price includes labor, materials, and equipment.
[2] Present Worth values based on a net discount rate of 5% over 30 years
[3] Calculated as Contingency Multiplier times Subtotal Non-Contractor Direct Costs

Table 5-C-11
Waukegan Manufactured Gas & Coke Plant Site
Remediation Contractor Capital Costs
Cost Estimate Details

Alternative 2: Containment
Vadose Zone Soil
Option 2C: Containment
Representative Volume

ITEM	ESTIMATED QUANTITY	UNIT	UNIT DIRECT COST [1]	ITEM TOTAL DIRECT COST		SOURCE	COMMENTS
GENERAL REQUIREMENTS							
Submittals	1	LS	$20,000	$20,000		BARR	Includes contractor preparation of submittals which include work plans, QA plans, drawings, etc.
Office	7	MO	$900	$6,300		MEANS	Rental of 2 - 50' x 12' trailers w/ AC
Mobilization	1	LS	$446,000	$446,000		BARR	10% of construction costs
Decontamination and Demobiliztion	1	LS	$223,000	$223,000		BARR	5% of construction costs
Utilities	7	MO	$600	$4,200		BARR	Estimate for FAX, telephone, toilets, heat, electricity, water, trash
Potable Water	7	MO	$800	$5,600		BARR	Includes delivered bottled water at 150 gal/week and rental of two coolers.
SUBTOTAL GENERAL REQUIREMENTS:					$705,000		
SITE WORK							
Connect Utilities	1	LS	$5,000	$5,000		BARR	Includes connection of telephone and electricity to offices.
Runon/runoff Control	1	LS	$10,000	$10,000		BARR	Install berms, silt fence, drainage ditches.
Clear and Grub	13.2	AC	$4,500	$59,400		MEANS	Clear and grub brush, including stumps
Dust Control	7	MO	$4,000	$28,000		BARR	Labor and equipment for 2 hrs/day
Ambient Air Monitoring	7	MO	$15,000	$105,000		BARR	Estimate for monitoring from 3 sampling stations for metals, SVOCs, VOCs, particulates.
Vehicle Decontamination Pad	7	LS	$4,000	$28,000		BARR	Construct a lined treatment decon area.
Vehicle Decontamination	7	MO	$5,000	$35,000		BARR	Cost for steam cleaning and operator for decon of all vehicles and equipment leaving the site.
Personal Decontamination	7	MO	$1,900	$13,300		HAZCON	18'x24' trailer with negative air and 4 showers. Includes transportation.
Water Storage Tanks	7	MO	$5,000	$35,000		BARR	Assume 2 Baker tanks
Access Improvement, Relocate Fence	1	LS	$15,000	$15,000		BARR	Site improvements
SUBTOTAL SITE WORK:					$334,000		
VAULT SUBGRADE PREPARATION							
Strip and Stockpile Overburden	10,700	CY	$3	$32,100		BARR	Assume 6" overburden across site
Subgrade Excavation and Stockpiling, and Debris Management and Soil Segregation	33,600	CY	$10	$336,000		BARR	5' Excavation beneath proposed vault location
De-watering, Pre-treatment, Disposal of Water During Excavation	300	1,000 Gal	$400	$120,000		BARR	Treatment through treatment system ($0.30/gal), discharge to POTW ($0.10/gal)
Backfill and Compact Subgrade							Backfill to 3' below existing ground
On-Site Material (Designated Soil Stockpile)	5,000	CY	$5	$25,000		BARR	
Off-Site Material	8,500	CY	$12	$102,000		BARR	Includes $10/cy for material and delivery to site and $2/cy for installation
SUBTOTAL VAULT SUBGRADE PREPARATION:					$615,000		
VAULT & COVER CONSTRUCTION AND APPURTENANCES							
BERM	7,900	CY	$5	$39,500		BARR	Assume on-site material from subgrade excavation
LINER							
Secondary Liner - Composite Liner							
Compacted clay - 3 ft	10,500	CY	$15	$157,500		LAKE COUNTY	Includes $10/cy for delivery to site, $5/cy for processing, placing, and compacting
60-mil HDPE membrane	122,200	SF	$0.85	$103,900		BARR	Add 10% to total surface area quantity to account for anchor trenches
Granular drainage material - 12 in	3,500	CY	$15	$52,500		MIDWEST AGG.	
6-inch HDPE collection pipe with aggregate filter	1,500	LF	$25	$37,500		BARR/MIDWEST AGG.	Leachate collection/Leak detection system, includes coarse aggregate filter
Primary Liner							
60-mil HDPE membrane	122,200	SF	$0.85	$103,900		BARR	Add 10% to total surface area quantity to account for anchor trenches
Granular drainage material - 12 in	3,500	CY	$15	$52,500		MIDWEST AGG.	
6-inch HDPE collection pipe with aggregate filter	1,500	LF	$25	$37,500		BARR/MIDWEST AGG.	Leachate collection, includes coarse aggregate filter
COVER							
Protective Cover - 6 in granular drainage material	2,000	CY	$15	$30,000		MIDWEST AGG.	
Low Permeability Layer							
40-mil LDPE membrane	109,000	SF	$0.75	$81,800		BARR	
Final Protective Layer							
Granular drainage material - 12 in	4,000	CY	$15	$60,000		MIDWEST AGG.	
Perforated drain tile with pea gravel filter	1,000	LF	$5	$5,000		MEANS	Installed at perimeter of cap, includes $2/lf for drain tile, $3/lf for pea gravel
Rooting zone material - 18 in	6,100	CY	$12	$73,200		BARR	Includes $10/cy for material and delivery to site, $2/cy for installation
Topsoil - 6 in	2,000	CY	$16	$32,000		BARR	Includes $14/cy for material and delivery to site, $2/cy for installation
Gas Vents	6	EA	$400	$2,400		BARR	
MISCELLANEOUS							
Leachate Storage Tank	1	EA	$55,000	$55,000		BARR	
Leachate Manhole	1	EA	$11,000	$11,000		BARR	
Leachate Pump and Controls	1	LS	$11,000	$11,000		BARR	
Leachate Pre-treatment System	1	LS	$10,000	$10,000		BARR	
Leachate Treatment During Construction	1	LS	$10,000	$10,000		BARR	
Site Perimeter Fence	1	LS	$35,000	$35,000		BARR	6' chain link fence ($20/LF) w/ barbed wire and 20' wide gate
SUBTOTAL VAULT & COVER CONSTRUCTION AND APPURTENANCES:					$1,001,000		

Table 5-C-11 (continued)
Waukegan Manufactured Gas & Coke Plant Site
Remediation Contractor Capital Costs
Cost Estimate Details

Alternative 2: Containment
Vadose Zone Soil
Option 2C: Containment
Representative Volume

ITEM	ESTIMATED QUANTITY	UNIT	UNIT DIRECT COST [1]	ITEM TOTAL DIRECT COST		SOURCE	COMMENTS
WASTE EXCAVATION AND HAULING							
Remove Existing Asphalt	7,200	SY	$5	$36,000		MEANS	OMC Driveway (South of Site)
Asphalt Disposal	1,800	CY	$30	$54,000		BARR	Recycle, Includes transportation and disposal
Excavate Soil, Segregate PAH and Arsenic Soil	17,600	CY	$20	$352,000		BARR	14,300 cy of PAH Remediation Zone Material and 3,300 cy of Arsenic Remediaton Zone Material
Load and Haul Remediaton Zone Material	12,500	CY	$5	$62,500		BARR	Assumes 20% swell during excavation and hauling
Place and Compact Soil in Containment Unit							
and Management of Debris	10,400	CY	$10	$104,000		BARR	
De-watering, Pre-treatment, Disposal of Water	770	1,000 Gal	$400	$308,000		BARR	Treatment through treatment system ($0.30/gal), discharge to POTW ($0.10/gal)
Backfill From Off-site Source	10,400	CY	$12	$124,800		BARR	Includes $10/cy for material and delivery to site, $2/cy for installation
SUBTOTAL WASTE EXCAVATION AND HAULING:					$1,041,000		
ASPHALT CAPPING							
CAP CONSTRUCTION							
Import Fill for Grading/Shaping	14,600	CY	$12	$175,200		BARR	One foot cover over cap area
Aggregate Subbase	14,600	CY	$15	$219,000		BARR	12" Thick
Prepare and Roll Subbase	43,700	SY	$1	$43,700		MEANS	
Asphalt Wear Course	43,700	SY	$8	$349,600		MEANS	3" Thick
Asphalt Berm Curb	3,000	LF	$2	$6,000		MEANS	
MISCELLANEOUS							
Re align Storm Sewer	500	LF	$70	$35,000		BARR	Includes restoration of lawn, parking lot, and manholes
De-watering Pre treatment Disposal of Water During							
Storm Sewer Work	1	LS	$20,000	$20,000		BARR	
Abandon Monitoring Wells	4	EA	$3,000	$12,000		BARR	MW-9S,D: MW-7S,D
SUBTOTAL ASPHALT CAPPING:					$861,000		
STORMWATER DETENTION POND AND APPURTENANCES							
Catch Basins	4	EA	$2,000	$8,000		BARR	1 Catch Basin/2 acres of cap
Piping Between Catch Basins	2,000	LF	$50	$100,000		BARR	
Manholes	2	EA	$2,500	$5,000		BARR	
Excavation	24,000	CY	$10	$240,000		BARR	
HDPE Liner	152,500	SF	$0.85	$129,625		BARR	
Backfill	2,800	CY	$5	$14,000		BARR	On-site material
Outlet Structure	1	EA	$10,000	$10,000		BARR	
Outlet Pipe	150	LF	$75	$11,250		BARR	Outlet to harbor
SUBTOTAL STORMWATER DETENTION POND AND APPURTENANCES:					$518,000		
SITE RESTORATION							
Restore Asphalt							OMC Driveway (South of Site)
Aggregate Subbase	970	CY	$15	$14,600		BARR	
Prepare and Roll Subbase	2,900	SY	$1	$2,900		MEANS	
Asphalt Wear Course	2,900	SY	$8	$23,200		MEANS	
Misc. Grading, Establish Drainage,							
Re-spread Topsoil	1	LS	$10,000	$10,000		BARR	
Turf Establisment, Temporary Erosion Control	8	AC	$5,000	$40,000		BARR	
SUBTOTAL SITE RESTORATION:					$91,000		
ESTIMATED TOTAL FIELD COST				$5,166,000			
Bonds (3%)				$155,000			
Insurance (2%)				$103,000			
Contingencies (15%)				$775,000 [2]			
ESTIMATED TOTAL CONTRACTOR CONSTRUCTION COST:					$6,200,000		

NOTES:
[1] Unit direct cost includes labor, materials, equipment, overhead, and profit.
[2] Calculated as Contingency Multiplier times Estimated Total Field Cost

Table 5-C-12
Waukegan Manufactured Gas & Coke Plant Site
Non-Contractor Capital Costs
Cost Estimate Details

Alternative 2: Containment
Vadose Zone Soil
Option 2C: Containment
Representative Volume

ITEM	ESTIMATED QUANTITY	UNIT	UNIT DIRECT COST [1]	ITEM TOTAL DIRECT COST		SOURCE	COMMENTS
Remedial Design Investigation							
Soil TCLP Analyses	1	LS	$5,000	$5,000		BARR	
Regulatory Oversight	7	MO	$50,000	$350,000		BARR	
Design	1	LS	$425,000	$425,000		BARR	Includes Work Plan, Design, Construction QAPP, Remedial Action Plan, PHASP, and meetings
Permits/Permitting Assistance	1	LS	$150,000	$150,000		BARR	
Engineering Services for Remedial Action	7	MO	$15,000	$105,000		BARR	Includes meetings, design scope changes, etc.
Construction Documentation							
Field engineering/construction observation	7	MO	$25,000	$175,000		BARR	Includes monitoring daily field activities during construction
Construction documentation report	1	LS	$55,000	$55,000		BARR	Final report - Includes data, statistical clean-up verification analysis, post-remedy soil management plan
Material testing	1	LS	$103,000	$103,000		BARR	2% of construction costs
SUBTOTAL NON-CONTRACTOR COSTS					$1,368,000		
CONTINGENCY (15%)					$205,000 [2]		
ESTIMATED TOTAL NON-CONTRACTOR CAPITAL COST					$1,570,000		

NOTES
[1] Unit price includes labor, materials, and equipment
[2] Calculated as Contingency Multiplier times Subtotal Non-Contractor Direct Costs

Table 5-C-13
Waukegan Manufactured Gas & Coke Plant Site
Operation, Maintenance, and Repair Costs
Cost Estimate Details

Alternative 2: Containment
Vadose Zone Soil
Option 2C: Containment
Representative Volume

ITEM	ESTIMATED QUANTITY	UNIT	UNIT DIRECT COST [1]	ANNUAL ITEM TOTAL DIRECT COST	FUTURE ITEM TOTAL DIRECT COST	YEAR FUTURE COST OCCURS	PRESENT WORTH OF DIRECT COST [2]	EQUIVALENT ANNUAL COST [2]	SOURCE	COMMENTS
Administration, Inspection, Annual Report	1	LS	$15,000	$15,000			$231,000	$15,000	BARR	
Analysis Review (every 5 years)	1	LS	$50,000			2003, 2008,...	$139,000	$9,000	BARR	
Regulatory Oversight	1	LS	$11,000	$11,000			$169,000	$11,000	BARR	
Maintain Final Cover	1	LS	$2,500	$2,500			$38,000	$3,000	BARR	
Leachate Collection, Treatment, Disposal	1	LS	$10,000	$10,000			$154,000	$10,000	BARR	
SUBTOTAL OM&R COSTS							$731,000	$48,000		
CONTINGENCY (15%)							$110,000	$7,000 [3]		
ESTIMATED TOTAL OPERATION, MAINTENANCE, AND REPAIR COST:							$840,000	$60,000		

NOTES.
[1] Unit price includes labor, materials, and equipment
[2] Present Worth values based on a net discount rate of 5% over 30 years
[3] Calculated as Contingency Multiplier times Subtotal Non-Contractor Direct Costs

Table 5-C-14
Waukegan Manufactured Gas & Coke Plant Site   **Alternative 2: Containment**
Remediation Contractor Capital Costs   **Groundwater**
Cost Estimate Details [1]

ITEM	ESTIMATED QUANTITY	UNIT	UNIT DIRECT COST [2]	ITEM TOTAL DIRECT COST		SOURCE	COMMENTS
GENERAL REQUIREMENTS							
Submittals	1	LS	$20,000	$20,000		BARR	Includes contractor preparation of submittals which include work plans, QA plans, drawings, etc.
Office	7	MO	$900	$6,300		MEANS	Rental of 2 - 50' x 12' trailer w/ AC. 3 months for slurry wall construction, 4 months for cell install and s!
Mobilization	1	LS	$710,000	$710,000		BARR	10% of construction costs
Demobilization and Decontamination	1	LS	$350,000	$350,000		BARR	5% of construction costs
Utilities	7	MO	$600	$4,200		BARR	Estimate for FAX, telephone, toilets, heat, electricity, water, trash
Potable Water	7	MO	$800	$5,600		BARR	Includes delivered bottled water at 150 ga/week and rental of two coolers.
SUBTOTAL GENERAL REQUIREMENTS					$1,100,000		
SITE WORK							
Dust Control	4	MO	$4,000	$16,000		BARR	Labor and equipment for 2 hrs/day, during slurry wall activities.
Ambient Air Monitoring	4	MO	$15,000	$60,000		BARR	Estimate for monitoring from 3 sampling stations for metals, VOCs, particulates.
Vehicle Decontamination	2	MO	$5,000	$10,000		BARR	Cost for steam cleaning and operator for decon of all vehicles and equipment leaving the site.
Personal Decontamination	2	MO	$1,900	$3,800		HAZCON	18'x24' trailer with negative air and 4 showers. Includes transportation.
SUBTOTAL SITE WORK					$90,000		
Slurry Wall	100,000	SF	$20	$2,000,000		BARR	4,000 ft slurry wall, 30 ft deep
Groundwater Extraction Wells	2	WELL	$25,000	$50,000		BARR	Includes pumps, piping, and controls.
SUBTOTAL SLURRY WALL					$2,100,000		
GROUNDWATER EXTRACTION / INFILTRATION SYSTEM							
Groundwater pump	4	EA	$12,000	$48,000		NEEP SYSTEMS	EconoPump Multi-well jet system, one unit per cell.
Groundwater pump controls	4	EA	$20,000	$80,000			Power supply, controls, and plumbing
Piping - 24" diameter corrugated PEP	1800	LF	$35	$63,000		BARR	Conduit to house piping
Install manholes	10	EA	$2,500	$25,000		BARR	Manholes along conduit
Piping - 1" diameter	54000	LF	$2	$110,000		BARR	1" diameter polyethylene piping between wells and pump, and to reinjection cells.
36" RCP Under Road	260	LF	$75	$20,000		BARR	Casing pipe for well lines. Includes open cut and asphalt restoration
Install monitoring wells	30	WELL	$5,000	$150,000		BARR	Additional groundwater monitoring well nests.
SUBTOTAL GROUNDWATER EXTRACTION					$500,000		

NOTES:
[1] Includes costs through completion of treatment and disposal
[2] Unit direct cost includes labor, materials, equipment, overhead, and profit
[3] Calculated as Contingency Multiplier times Contractor Subtotal Direct Costs

Table 5-C-14 (continued)
Waukegan Manufactured Gas & Coke Plant Site   **Alternative 2: Containment**
Remediation Contractor Capital Costs   **Groundwater**
Cost Estimate Details [1]

ITEM	ESTIMATED QUANTITY	UNIT	UNIT DIRECT COST [2]	ITEM TOTAL DIRECT COST	SOURCE	COMMENTS
WATER TREATMENT - 60 GPM						
Utilities	1	LS	$30,000	$30,000	BARR	$15K power, $10K sewer, $5K water, telephone, etc.
Building for Treatment Equipment	4100	SF	$100	$410,000	BARR	
HVAC for Treatment Building	4100	SF	$10	$41,000	MEANS	
Electrical for Treatment Building	4100	SF	$9	$37,000	MEANS	
Concrete Slab / Footings	550	CY	$500	$280,000	BARR	Assumes 12" thick slab
System Assembly	1500	HR	$50	$75,000	BARR	
Pipes, Pumps & Equipment	1	LS	$150,000	$150,000	BARR	
Total System Startup	400	HR	$100	$40,000	BARR	
Startup Sampling	200	SMPL	$1,000	$200,000	BARR	
Field Pilot Study						
Equipment - Andco	6	MO	$20,000	$120,000	ANDCO	Andco equipment rental.
Equipment - Zimpro PACT	6	MO	$25,000	$150,000	ZIMPRO	Zimpro equipment rental.
Transportation of Equipment	1	LS	$5,000	$5,000	BARR	
Operation	6	MO	$5,800	$35,000	BARR	Operator 24 hours per week at $60 per hour.
Sampling	430	SMPL	$1,000	$430,000	BARR	14 sampling events, 30 samples per event, plus 6 samples over first 2 weeks.
Installation & Startup	200	HR	$100	$20,000	BARR	
Electrochemical Precipitation						
Equipment	1	LS	$160,000	$160,000	ANDCO	Arsenic removal.
Transportation of equipment	1	LS	$5,000	$5,000	ANDCO	
Installation & Startup	1	LS	$20,000	$20,000	BARR	Andco support for start-up.
Activated Sludge with PAC						
PACT System Equipment	1	LS	$600,000	$600,000	ZIMPRO	Phenol and organics removal.
Transportation & Installation	1	LS	$195,000	$195,000	ZIMPRO	
Activated Sludge with PAC - Ammonia						
PACT System Equipment	1	LS	$1,100,000	$1,100,000	ZIMPRO	Ammonia nitrification and denitrification (90%).
Transportation & Installation	1	LS	$300,000	$300,000	ZIMPRO	

SUBTOTAL WATER TREATMENT				$4,400,000	

SUBTOTAL CONTRACTOR DIRECT COST				$8,200,000	

BONDS (3%) $250,000
INSURANCE (2%) $160,000
CONTINGENCY [3] (15%) $1,200,000

ESTIMATED TOTAL CONTRACTOR CONSTRUCTION COST				$9,800,000	

NOTES:
[1] Includes costs through completion of treatment and disposal
[2] Unit direct cost includes labor, materials, equipment, overhead, and profit
[3] Calculated as Contingency Multiplier times Contractor Subtotal Direct Costs

Table 5-C-15
Waukegan Manufactured Gas & Coke Plant Site   **Alternative 2: Containment**
Non-Contractor Capital Costs   **Groundwater**
Cost Estimate Details [1]

ITEM	ESTIMATED QUANTITY	UNIT	UNIT DIRECT COST [2]	ITEM TOTAL DIRECT COST	SOURCE	COMMENTS
Remedial Design Investigation						
Groundwater monitoring wells	1	LS	$200,000	$200,000	BARR	Includes installation of 20 additional monitoring well nests, and geoprobe costs at $1200/day for 2 days
Groundwater sampling	1	LS	$50,000	$50,000	BARR	Sampling and analysis of 22 monitoring well nests and 6 geoprobes
Surface water sampling	1	LS	$100,000	$100,000	BARR	Includes 2 surface water sampling events at $50,000 each
Pilot Study						
Work Plan & Coordination	1	LS	$30,000	$30,000	BARR	Design.
Engineering Oversight	6	MO	$10,000	$60,000	BARR	Engineering oversight during pilot study.
Final Report	1	LS	$30,000	$30,000	BARR	Regulatory oversight during construction activities.
Remedial Design	1	LS	$350,000	$350,000	BARR	Includes work plan, treatment system, cell, and slurry wall design, QA/QC plan, SHSP, and meetings
Bidding/Bidding Administration	1	LS	$30,000	$30,000	BARR	
Permits/Permitting Assistance	1	LS	$50,000	$50,000	BARR	
Regulatory Oversight	7	MO	$22,500	$158,000	BARR	Regulatory oversight during construction activities.
Engineering Services for Remedial Action	6	MO	$15,000	$90,000	BARR	Includes construction meetings, changes to plans and specifications, etc.
Field engineering/construction observation	6	MO	$25,000	$150,000	BARR	Includes monitoring daily field activities for 6 months.
H & S Monitoring/Air Monitoring	3	MO	$7,000	$21,000	BARR	Includes health and safety specialist.
Slurry Wall Testing	1	LS	$40,000	$40,000	BARR	2% of slurry wall construction costs.
Construction documentation report	1	LS	$65,000	$65,000	BARR	Final report, including slurry wall testing documentation.

SUBTOTAL NON-CONTRACTOR COSTS				$1,400,000

CONTINGENCY (15%) [3] $210,000

ESTIMATED TOTAL NON-CONTRACTOR CAPITAL COST	$1,600,000

NOTES:
[1] Includes costs through completion of treatment and disposal
[2] Unit direct cost includes labor, materials, equipment, overhead, and profit
[3] Calculated as Contingency Multiplier times Contractor Subtotal Direct Costs

Table 5-C-16
Waukegan Manufactured Gas & Coke Plant Site
Operation, Maintenance, and Repair Costs
Cost Estimate Details [1]

Alternative 2: Containment
Groundwater

ITEM	ESTIMATED QUANTITY	UNIT	UNIT DIRECT COST [2]	ANNUAL ITEM TOTAL DIRECT COST	FUTURE ITEM TOTAL DIRECT COST	YEAR FUTURE COST OCCURS	PRESENT WORTH OF DIRECT COST [4]	EQUIVALENT ANNUAL COST [4]	SOURCE	COMMENTS
TREATMENT CELLS										Four treatment cells Installed and operated per year.
Sampling, Analysis, Reporting	1	LS	$200,000	$200,000			$900,000	$200,000	BARR	
Wellpoint Installation	120	WELL	$600	$72,000			$310,000	$72,000	MEANS	For one treatment cell: 10 pumping, 20 reinjection wells.
Additional Piping - 1" diameter	24000	LF	$2	$48,000			$210,000	$48,000	BARR	1" diameter polyethylene required for moving the treatment cells.
Repair, Maintenance	1	LS	$80,000	$80,000			$350,000	$80,000	BARR	Well and pump maintenance.
SUBTOTAL CELL OM&R COSTS							$1,800,000	$400,000		
years 1 - 5										
Engineering Oversight	500	HR	$100	$50,000			$220,000	$50,000	BARR	
WATER TREATMENT										
Heating and Cooling of Treatment Building	1	LS	$40,000	$40,000			$170,000	$40,000		Includes winter heating of outdoor tanks.
ELECTROCHEMICAL PRECIPITATION										
Annual Report	1	LS	$10,000	$10,000			$43,000	$10,000		Arsenic removal.
Sampling, Analysis, Reporting	30	SAMPLE	$500	$15,000			$65,000	$15,000		
Residual Transport and Disposal	20	TON	$100	$2,000			$9,000	$2,000	BARR	Disposal of Sludge in a Subtitle D Landfill
Labor for Operation	3000	HR	$50	$150,000			$650,000	$150,000		Operator assumed 8 hours per day, 7 days per week.
Power and Iron Costs	32000	1000 GAL	$0.33	$11,000			$48,000	$11,000		Cost per 1000 gallons treated.
PACT SYSTEM - PHENOL/ORGANICS REMOVAL										Phenol and organics removal.
Annual Report	1	LS	$10,000	$10,000			$43,000	$10,000		
Sampling, Analysis, Reporting	30	SAMPLE	$500	$15,000			$65,000	$15,000		
Residual Transport and Disposal	80	TON	$100	$8,000			$35,000	$8,000	BARR	Disposal of Sludge in a Subtitle D Landfill
Labor for Operation Optimization	3000	HR	$50	$150,000			$650,000	$150,000		Operator assumed 8 hours per day, 7 days per week.
Power and Chemical Costs	365	DAY	$95	$35,000			$150,000	$35,000		
PACT SYSTEM - AMMONIA REMOVAL										Ammonia nitrification and denitrification (90%).
Annual Report	1	LS	$10,000	$10,000			$43,000	$10,000		
Sampling, Analysis, Reporting	30	SAMPLE	$500	$15,000			$65,000	$15,000		
Residual Transport and Disposal	80	TON	$100	$8,000			$35,000	$8,000	BARR	Disposal of Sludge in a Subtitle D Landfill
Labor for Operation Optimization	3000	HR	$50	$150,000			$650,000	$150,000		Operator assumed 8 hours per day, 7 days per week.
Power and Chemical Costs	365	DAY	$165	$60,000			$260,000	$60,000		
Carbon Source Addition for Denitrification	365	DAY	$100	$37,000			$160,000	$37,000		
Groundwater Monitoring	160	SAMPLE	$1,000	$160,000			$700,000	$160,000		
SUBTOTAL WATER TREATMENT OM&R COSTS (years 1-5)							$4,100,000	$940,000		
TREATMENT EQUIPMENT (years 1-5)										
Pipes, Pumps, and Equipment	1	LS	$15,000	$15,000			$65,000	$15,000	BARR	10% of equipment capital cost
Electrochemical Precipitation Equipment	1	LS	$32,000	$32,000			$140,000	$32,000	BARR	20% of equipment capital cost
PACT System Equipment	1	LS	$24,000	$24,000			$100,000	$24,000	BARR	4% of equipment capital cost
PACT System Equipment - Ammonia Removal	1	LS	$44,000	$44,000			$190,000	$44,000	BARR	4% of equipment capital cost
SUBTOTAL TREATMENT EQUIPMENT M&R COSTS (years 1-5)							$500,000	$120,000		

NOTES:
[1] Includes costs through completion of treatment and disposal.
[2] Unit direct cost includes labor, materials, equipment, overhead, and profit.
[3] Calculated as Contingency Multiplier times Subtotal Direct Costs
[4] Present Worth values based on a net discount rate of 5% over 5 years

Table 5-C-16 (continued)
Waukegan Manufactured Gas & Coke Plant Site   **Alternative 2: Containment**
Operation, Maintenance, and Repair Costs   **Groundwater**
Cost Estimate Details [1]

ITEM	ESTIMATED QUANTITY	UNIT	UNIT DIRECT COST [2]	ANNUAL ITEM TOTAL DIRECT COST	FUTURE ITEM TOTAL DIRECT COST	YEAR FUTURE COST OCCURS	PRESENT WORTH OF DIRECT COST [4]	EQUIVALENT ANNUAL COST [4]	SOURCE	COMMENTS
years 6 - 30										
Engineering Oversight	100	HR	$100	$10,000			$110,000	$7,800	BARR	
										Cells are no longer operating.
WATER TREATMENT										Treatment of water withdrawn from within slurry wall only, approx 1Gl
Heating and Cooling of Treatment Building	1	LS	$40,000	$40,000			$440,000	$31,200		
ELECTROCHEMICAL PRECIPITATION										
Annual Report	1	LS	$10,000	$10,000			$110,000	$7,800		Arsenic removal.
Sampling, Analysis, Reporting	30	SAMPLE	$500	$15,000			$170,000	$12,100		
Residual Transport and Disposal	0.3	TON	$100	$30			$330	$20	BARR	Disposal of Sludge in a Subtitle D Landfill (1/60 of quantity for 0-5 ye.
Labor for Operation	750	HR	$50	$37,500			$410,000	$29,000		Operator assumed 2 hours per day, 7 days per week.
Power and Iron Costs	530	1000 GAL	$0.33	$200			$2,000	$100		Cost per 1000 gallons treated.
PACT SYSTEM - PHENOL/ORGANICS REMOVAL										Phenol and organics removal.
Annual Report	1	LS	$10,000	$10,000			$110,000	$7,800		
Sampling, Analysis, Reporting	30	SAMPLE	$500	$15,000			$170,000	$12,000		
Residual Transport and Disposal	1.3	TON	$100	$130			$1,000	$70	BARR	Disposal of Sludge in a Subtitle D Landfill (1/60 of quantity for 0-5 ye.
Labor for Operation Optimization	750	HR	$50	$37,500			$410,000	$29,000		Operator assumed 2 hours per day, 7 days per week.
Power and Chemical Costs	365	DAY	$24	$9,000			$99,000	$7,000		
PACT SYSTEM - AMMONIA REMOVAL										Ammonia nitrification and denitrification (90%).
Annual Report	1	LS	$10,000	$10,000			$110,000	$7,800		
Sampling, Analysis, Reporting	30	SAMPLE	$500	$15,000			$170,000	$12,000		
Residual Transport and Disposal	1.3	TON	$100	$130			$1,000	$70	BARR	Disposal of Sludge in a Subtitle D Landfill (1/60 of quantity for 0-5 ye.
Labor for Operation Optimization	750	HR	$50	$38,000			$420,000	$30,000		Operator assumed 2 hours per day, 7 days per week.
Power and Chemical Costs	365	DAY	$41	$15,000			$170,000	$12,000		
Carbon Source Addition for Denitrification	365	DAY	$25	$9,100			$100,000	$7,100		
Groundwater Monitoring	160	SAMPLE	$1,000	$160,000			$1,800,000	$130,000		
SUBTOTAL WATER TREATMENT OM&R COSTS (years 6-30)							$4,800,000	$340,000		
TREATMENT EQUIPMENT (years 6-30)										
Replace Wells (every 10 years)	2	WELL	$25,000	$50,000		2008, 2018	$50,000	$3,300		
Pipes, Pumps, and Equipment	1	LS	$2,000	$2,000			$22,000	$1,600	BARR	1% of equipment capital cost, due to lower flow.
Electrochemical Precipitation Equipment	1	LS	$3,200	$3,200			$35,000	$2,500	BARR	2% of equipment capital cost, due to lower flow.
PACT System Equipment	1	LS	$2,400	$2,400			$27,000	$1,900	BARR	0.4% of equipment capital cost, due to lower flow.
PACT System Equipment - Ammonia Removal	1	LS	$4,400	$4,400			$49,000	$3,500	BARR	0.4% of equipment capital cost, due to lower flow.
SUBTOTAL TREATMENT EQUIPMENT M&R COSTS (years 6-30)							$180,000	$13,000		
MONITORED NATURAL ATTENUATION										
Groundwater Monitoring	160	SAMPLE	$1,000	$160,000			$2,500,000	$160,000		
Data Evaluation/Modeling	1	LS	$10,000	$10,000			$150,000	$10,000	BARR	
Admin, Inspection, Annual Report	1	LS	$50,000	$50,000			$770,000	$50,000	BARR	
Five Year Review	1	LS	$60,000			2003	$60,000	$3,900		
Regulatory Oversight	1	LS	$10,000	$10,000			$150,000	$10,000	BARR	
SUBTOTAL MONITORED NATURAL ATTENUATION							$3,600,000	$230,000		
SUBTOTAL OM&R COSTS							$15,000,000	$2,000,000		
CONTINGENCY [3] (15%)							$2,300,000	$300,000		
ESTIMATED TOTAL OM&R COSTS							$17,300,000	$2,300,000		

NOTES:
[1] Includes costs through completion of treatment and disposal.
[2] Unit direct cost includes labor, materials, equipment, overhead, and profit.
[3] Calculated as Contingency Multiplier times Subtotal Direct Costs
[4] Present Worth values based on a net discount rate of 5% over 30 years

Table 5-C-17
Waukegan Manufactured Gas & Coke Plant Site
Remediation Contractor Capital Costs
Cost Estimate Details

Alternative 3: Removal
Vadose Zone Soil
Option 3A: Treatment
Representative Volume

ITEM	ESTIMATED QUANTITY	UNIT	UNIT DIRECT COST [1]	ITEM TOTAL DIRECT COST		SOURCE	COMMENTS
GENERAL REQUIREMENTS							
Submittals	1	LS	$20,000	$20,000		BARR	Includes contractor preparation of submittals which include work plans, QA plans, drawings, etc
Office	6	MO	$900	$5,400		MEANS	Rental of 2 - 50' x 12' trailer w/ AC
Mobilization	1	LS	$423,700	$423,700		BARR	10% of construction costs, does not include disposal
Demobilization and Decontamination	1	LS	$211,850	$211,850		BARR	5% of construction costs, does not inclued disposal
Utilities	6	MO	$600	$3,600		BARR	Estimate for FAX, telephone, toilets, heat, electricity, water, trash
Potable Water	6	MO	$800	$4,800		BARR	Includes delivered bottled water at 150 ga/week and rental of two coolers
SUBTOTAL GENERAL REQUIREMENTS:					$669,000		
SITE WORK							
Connect Utilities	1	LS	$5,000	$5,000		BARR	Includes connection of telephone and electricity to offices
Runon/runoff Control	1	LS	$10,000	$10,000		BARR	Install berms, silt fence, drainage ditches
Clear, Grub, and Subgrade Preparation	11.0	AC	$4,500.00	$49,440		MEANS	Clear & Grub brush, including stumps (assume half of site)
Dust Control	6	MO	$4,000	$24,000		BARR	Labor and equipment for 2 hrs/day
Ambient Air Monitoring	6	MO	$15,000	$90,000		BARR	Estimate for monitoring from 3 sampling stations for metals, VOCs, particulates
Vehicle Decontamination Pad	1	LS	$4,000	$4,000		BARR	Construct a lined treatment decon area.
Vehicle Decontamination	6	MO	$5,000	$30,000		BARR	Cost for steam cleaning and operator for decon of all vehicles and equipment leaving the site
Personal Decontamination	6	MO	$1,900	$11,400		HAZCON	18'x24' trailer with negative air and 4 showers. Includes transportation
Water Storage Tanks	6	MO	$5,000	$30,000		BARR	Assume 2 Baker tanks
Access Improvements, Relocate Fence	1	LS	$10,000	$10,000		BARR	Site Improvements
SUBTOTAL SITE WORK:					$264,000		
EXCAVATION, TREATMENT, DISPOSAL, AND BACKFILL							
PAH REMEDIATION ZONE							
Set Up Processing and Stockpile Area	1	LS	$100,000	$100,000		BARR	Concrete pad for soil processing equipment, asphalt pad, concrete walls for staging
Strip and Stockpile Overburden	8,900	CY	$3	$26,700		BARR	Assume 6" Overburden in excavation areas (assume half of site)
Remove Existing Asphalt	7,200	SY	$5	$36,000		MEANS	OMC Driveway (South of Site)
Asphalt Disposal	1,800	CY	$30	$54,000		BARR	Recycle
Excavate Soil, Separate PAH Material, and Segregate Debris	14,300	CY	$20	$286,000		BARR	7,100 CY of tar & oily soil, 7,200 cy of overburden
Soil Mixing and Loading	16,000	Ton	$40	$640,000		BARR	Screening to segregate debris and mixing with coal (50% by wt) and other on-site soil to render non-hazardou
Sampling and Testing Processed Material	16,000	Ton	$10	$160,000		BARR	TCLP analysis
Load and Haul Processed Material to Power Plant	16,000	Ton	$60	$960,000		KIPIN	Illinois Power, Baldwin power plant near East St. Louis
Thermal Treatment	16,000	Ton	$50	$800,000		KIPIN	
Clean Debris	2,100	Ton	$20	$42,000		BARR	Debris consists of bricks, rebar, concerete,timber, and pipe; assume 10% debris by weigh
Load and Haul Debris to Local Landfill	2,100	Ton	$10	$21,000		BARR	
Debris Disposal at Landfill	2,100	Ton	$20	$42,000		BARR	
Dewatering, Pre-Treatment, and Disposal of Water During Excavation	770	1,000 Gal	$400	$308,000		BARR	Treatment through treatment system ($0.30/gal), discharge to POTW ($0.10/gal)
ARSENIC REMEDIATON ZONE							
Excavate Soil and Segregate Debris	3,300	CY	$20	$66,000		BARR	
Soil Stabilization and Stockpiling	5,000	Ton	$80	$400,000		BARR	
Sampling and Testing Processed Material	5,000	Ton	$10	$50,000		BARR	TCLP analysis
BACKFILL							
Backfill and Compact Stabilized Material	4,000	CY	$15	$60,000		BARR	
Load, Haul, Backfill, and Compact Soil from Designated Stockpile and Overburder	12,200	CY	$5	$61,000		BARR	
Backfill from Off-Site Source	2,100	CY	$12	$25,200		BARR	Includes $10/cy for material and delivery to site and $2/cy for installation
SUBTOTAL EXCAVATION, TREATMENT, DISPOSAL, AND BACKFILL:					$4,138,000		

Table 5-C-17 (continued)
Waukegan Manufactured Gas & Coke Plant Site
Remediation Contractor Capital Costs
Cost Estimate Details

Alternative 3: Removal
Vadose Zone Soil
Option 3A: Treatment
Representative Volume

ITEM	ESTIMATED QUANTITY	UNIT	UNIT DIRECT COST [1]	ITEM TOTAL DIRECT COST		SOURCE	COMMENTS
PHYTOREMEDIATION CAPPING							
SUBGRADE PREPARATION							
Soil Sampling and Analysis	1	LS	$5,000	$5,000		BARR	Nutrient content, compaction, salts, pH
Misc. Grading, Establish Drainage	1	LS	$10,000	$10,000		BARR	
Deep Tilling, Harrow	22	AC	$500.00	$11,000		BARR	Seedbed Preparation
6 inch layer of fill	17,725	CY	$12.00	$213,000		BARR	6" fill layer for phytoremediation cap area
ESTABLISH VEGETATION (3 ZONES)							
OILY ZONE							
Plant Trees	1,200	EA	$140	$168,000		BARR	Mulberry trees planted 15 ft on center
Seed	6	AC	$4,000	$24,000		BARR	Plant grass
Hydromulch	6	AC	$1,000	$6,000		BARR	Erosion Protection
MODERATELY CONTAMINATED ZONE							
Seed	8	AC	$4,000	$32,000		BARR	Plant grass
Hydromulch	8	AC	$1,000	$8,000		BARR	Erosion Protection
LOW CONTAMINATED ZONE							
Seed	8	AC	$4,000	$32,000		BARR	Plant grass
Hydromulch	8	AC	$1,000	$8,000		BARR	Erosion Protection
MISCELLANEOUS							
Re-align Storm Sewer	500	LF	$70	$35,000		BARR	Includes restoration of lawn, parking lot, and manholes
De-watering/Pre-treatment, Disposal of Water During							
Storm Sewer Work	1	LS	$20,000	$20,000		BARR	Treatment through treatment system ($0.30/gal), discharge to POTW ($0.10/gal)
Abandon Monitoring Wells	4	EA	$3,000	$12,000		BARR	MW-9S,D: MW-7S,D
SUBTOTAL PHYTOREMEDIATION CAPPING:					$584,000		
SITE RESTORATION							
Restore Asphalt							OMC Driveway (South of Site)
Aggregate Subbase	970	CY	$15	$14,550		BARR	
Prepare and Roll Subbase	2,900	SY	$1	$2,900		MEANS	
Asphalt Wear Course	2,900	SY	$8	$23,200		MEANS	
Misc. Grading, Establish Drainage,							
Re-spread Topsoil	1	LS	$10,000	$10,000		BARR	
SUBTOTAL SITE RESTORATION:					$51,000		
ESTIMATED TOTAL FIELD COST				$5,706,000			
ESTIMATED TOTAL FIELD COST, EXCLUDING DISPOSAL				$4,906,000			
Bonds (3%)				$147,000			Does not include Disposal Costs for PAH Remediation Zone material.
Insurance (2%)				$98,000			Does not include Disposal Costs for PAH Remediation Zone material.
Contingencies (15%)				$856,000 [2]			
ESTIMATED TOTAL CONTRACTOR CONSTRUCTION COST:				$6,807,000			

NOTES:
[1] Unit direct cost includes labor, materials, equipment, overhead, and profit.
[2] Calculated as Contingency Multiplier times Estimated Total Field Cost

Table 5-C-18
Waukegan Manufactured Gas & Coke Plant Site
Non-Contractor Capital Costs
Cost Estimate Details

Alternative 3: Removal
Vadose Zone Soil
Option 3A: Treatment
Representative Volume

ITEM	ESTIMATED QUANTITY	UNIT	UNIT DIRECT COST [1]	ITEM TOTAL DIRECT COST		SOURCE	COMMENTS
Remedial Design Investigation							
Arsenic Stabilization Treatability Study	1	LS	$30,000	$30,000		BARR	
Soil TCLP Analyses	1	LS	$5,000	$5,000		BARR	
Regulatory Oversight	6	MO	$22,500	$135,000		BARR	
Design	1	LS	$250,000	$250,000		BARR	Includes Work Plan, Design, Construction QAPP, Remedial Action, PHASP, and meetings
Permits/Permitting Assistance	1	LS	$100,000	$100,000			
Engineering Services During Remedial Action	6	MO	$15,000	$90,000		BARR	Includes meetings, design scope changes, etc
Construction Documentation							
Field engineering/construction observation	6	MO	$15,000	$90,000		BARR	Includes monitoring daily field activities during construction
Construction documentation report	1	LS	$55,000	$55,000		BARR	Final report - Includes data, statistical clean-up verification analysis, post-remedy soil management plan
Material testing	1	LS	$98,000	$98,000		BARR	2% of construction costs
SUBTOTAL NON-CONTRACTOR COSTS					$853,000		
CONTINGENCY (15%)					$128,000	[2]	
ESTIMATED TOTAL NON-CONTRACTOR CAPITAL COST:					$980,000		

NOTES:
[1] Unit price includes labor, materials, and equipment
[2] Calculated as Contingency Multiplier times Subtotal Non-Contractor Direct Costs

Table 5-C-19
Waukegan Manufactured Gas & Coke Plant Site
Operation, Maintenance, and Repair Costs
Cost Estimate Details

Alternative 3: Removal
Vadose Zone Soil
Option 3A: Treatment
Representative Volume

ITEM	ESTIMATED QUANTITY	UNIT	UNIT DIRECT COST [1]	ITEM TOTAL DIRECT COST	FUTURE ITEM TOTAL DIRECT COST	YEAR FUTURE COST OCCURS	PRESENT WORTH OF DIRECT COST[2]	EQUIVALENT ANNUAL COST[2]	SOURCE	COMMENTS
Administration, Inspection, Annual Report	1	LS	$15,000	$15,000			$231,000	$15,000	BARR	
Analysis Review (every 5 years)	1	LS	$11,000			2002	$31,000	$2,000	BARR	
Regulatory Oversight	1	LS	$11,000	$11,000			$169,000	$11,000	BARR	
Maintain Phytoremediation Cover										
Maintenance (first two years)	1	LS	$20,000				$37,188	$2,421	BARR	Includes monthly mowing, spraying for weeds
Maintenance (year two through four)	1	LS	$10,000				$16,865	$1,098	BARR	
Maintenance (after year four)	1	LS	$5,000				$59,133	$3,850	BARR	
Replace Trees (first year)	240	EA	$140	$33,600			$32,001	$2,083	BARR	Replace 20% of trees
Replace Trees (second year)	120	EA	$140	$16,800			$15,238	$992	BARR	Replace 10% of trees
Replace Grass (first year)	4	AC	$4,000	$17,600			$16,762	$1,091	BARR	Re-plant 20% of grass
Watering (first year)	1	LS	$20,000	$20,000			$19,048	$1,240	BARR	
Bi-weekly Inspection (first year)	48	HR	$50	$2,400			$2,286	$149	BARR	Bi-weekly inspection (4-hrs per inspection) for 6 months
Monthly Inspection (after first year)	24	HR	$50	$1,200			$17,304	$1,126	BARR	Weekly inspection (4-hrs per inspection) for 6 months
Folage/Berry Analysis (first two years)	1	LS	$6,000	$6,000			$11,156	$726	BARR	Assumes 10 samples/month at $100/sample for 6 months
Folage/Berry Analysis (after year two)	1	LS	$3,000	$3,000			$40,539	$2,639	BARR	Assumes 5 samples/month at $100/sample for 6 months
SUBTOTAL OM&R COSTS							$699,000	$45,000		
CONTINGENCY (15%)							$105,000	$7,000 [3]		
ESTIMATED TOTAL OPERATION, MAINTENANCE, AND REPAIR COST:							$804,000	$52,000		

NOTES
[1] Unit price includes labor, materials, and equipment.
[2] Present Worth values based on a net discount rate of 5% over 30 years
[3] Calculated as Contingency Multiplier times Subtotal Non-Contractor Direct Costs

Table 5-C-20
Waukegan Manufactured Gas & Coke Plant Site
Remediation Contractor Capital Costs
Cost Estimate Details

Alternative 3: Removal
Vadose Zone Soil
Option 3B: Disposal
Representative Volume

ITEM	ESTIMATED QUANTITY	UNIT	UNIT DIRECT COST [1]	ITEM TOTAL DIRECT COST		SOURCE	COMMENTS
GENERAL REQUIREMENTS							
Submittals	1	LS	$20,000	$20,000		BARR	Includes contractor preparation of submittals which include work plans, QA plans, drawings, etc
Office	6	MO	$900	$5,400		MEANS	Rental of 2 - 50' x 12' trailer w/ AC
Mobilization	1	LS	$298,000	$298,000		BARR	10% of construction costs, does not include disposal
Demobilization and Decontamination	1	LS	$149,000	$149,000		BARR	5% of construction costs, does not inclued disposal
Utilities	6	MO	$600	$3,600		BARR	Estimate for FAX, telephone, toilets, heat, electricity, water, trash
Potable Water	6	MO	$800	$4,800		BARR	Includes delivered bottled water at 150 ga/week and rental of two coolers
SUBTOTAL GENERAL REQUIREMENTS:					$481,000		
SITE WORK							
Connect Utilities	1	LS	$5,000	$5,000		BARR	Includes connection of telephone and electricity to offices
Runon/runoff Control	1	LS	$10,000	$10,000		BARR	Install berms, silt fence, drainage ditches
Clear, Grub, and Subgrade Preparation	11.0	AC	$4,500.00	$49,400		MEANS	Clear & Grub brush, including stumps (assume half of site)
Dust Control	6	MO	$4,000	$24,000		BARR	Labor and equipment for 2 hrs/day
Ambient Air Monitoring	1	MO	$15,000	$15,000		BARR	Estimate for monitoring from 3 sampling stations for metals, VOCs, particulates
Vehicle Decontamination Pad	1	LS	$4,000	$4,000		BARR	Construct a lined treatment decon area.
Vehicle Decontamination	6	MO	$5,000	$30,000		BARR	Cost for steam cleaning and operator for decon of all vehicles and equipment leaving the site
Personal Decontamination	6	MO	$1,900	$11,400		HAZCON	18'x24' trailer with negative air and 4 showers. Includes transportation
Water Storage Tanks	6	MO	$5,000	$30,000		BARR	Assume 2 Baker tanks
Access Improvements, Relocate Fence	1	LS	$10,000	$10,000		BARR	Site Improvements
SUBTOTAL SITE WORK					$189,000		
EXCAVATION, DISPOSAL, AND BACKFILL							
PAH REMEDIATION ZONE							
Strip and Stockpile Overburden	8,900	CY	$3	$26,700		BARR	Assume 6" Overburden Across Site
Remove Existing Asphalt	7,200	SY	$5	$36,000		MEANS	OMC Driveway (South of Site)
Asphalt Disposal	1,800	CY	$30	$54,000		BARR	Recycle, includes transportation and disposal
Excavate Soil, Separate PAH Material	14,300	CY	$20	$286,000		BARR	7,100 CY of tar & oily soil, 7,200 cy of overburden
Soil Mixing and Loading	11,000	Ton	$40	$440,000		BARR	Mix tar with oily soil to allow for handling, loading, and unloading
Sampling and Testing	11,000	Ton	$10	$110,000		BARR	
Load and Haul PAH Material	11,000	Ton	$33	$363,000		PDC	
Disposal at RCRA Subtitle C Landfill	11,000	Ton	$75	$825,000		PDC	Disposal in Peoria, IL
Dewatering, Pre-Treatment, and Disposal of Water During Excavation	770	1,000 Gal	$400	$308,000		BARR	Treatment through treatment system ($0.30/gal), discharge to POTW ($0.10/gal)
ARSENIC REMEDIATON ZONE							
Set Up Segregation Area and Equipment	1	LS	$100,000	$100,000		BARR	Concrete pad for soil processing equipment, asphalt pad, concrete walls for staging
Excavate Soil and Segregate Debris	3,300	CY	$20	$66,000		BARR	
Sampling and Testing	5,000	Ton	$10	$50,000		BARR	
Load and Haul Arsenic Material	5,000	Ton	$33	$165,000		PDC	
Disposal at RCRA Subtitle C Landfill	5,000	Ton	$100	$500,000		PDC	Includes stabilization of Arsenic and disposal in Peoria, IL
Clean Debris	500	Ton	$20	$10,000		BARR	Debris consists of bricks, rebar, concerete,timber, and pipe; assume 10% debris by weigh
Load and Haul Debris to Local Landfill	500	Ton	$10	$5,000		BARR	
Debris Disposal at Landfill	500	Ton	$20	$10,000		BARR	
BACKFILL							
Load, Haul, Backfill, and Compact Soil from Designated Stockpile and Overburder	12,200	CY	$5	$61,000		BARR	
Backfill from Off-Site Source	5,400	CY	$12	$64,800		BARR	Includes $10/cy for material and delivery to site and $2/cy for installation
SUBTOTAL EXCAVATION, TREATMENT, DISPOSAL, AND BACKFILL:					$3,481,000		

Table 5-C-20 (continued)
Waukegan Manufactured Gas & Coke Plant Site
Remediation Contractor Capital Costs
Cost Estimate Details

Alternative 3: Removal
Vadose Zone Soil
Option 3B: Disposal
Representative Volume

ITEM	ESTIMATED QUANTITY	UNIT	UNIT DIRECT COST [1]	ITEM TOTAL DIRECT COST		SOURCE	COMMENTS
PHYTOREMEDIATION CAPPING							
SUBGRADE PREPARATION							
Soil Sampling and Analysis	1	LS	$5,000	$5,000		BARR	Nutrient content, compaction, salts, pH
Misc. Grading, Establish Drainage	1	LS	$10,000	$10,000		BARR	
Deep Tilling, Harrow	22	AC	$500.00	$11,000		BARR	Seedbed Preparation
6 inch layer of fill	17,725	CY	$12.00	$213,000		BARR	6" fill layer for phytoremediation cap area
ESTABLISH VEGETATION (3 ZONES)							
OILY ZONE							
Plant Trees	1,200	EA	$140	$168,000		BARR	Mulberry trees planted 15 ft on center
Seed	6	AC	$4,000	$24,000		BARR	Plant grass
Hydromulch	6	AC	$1,000	$6,000		BARR	Erosion protection
MODERATELY CONTAMINATED ZONE							
Seed	8	AC	$4,000	$32,000		BARR	Plant grass
Hydromulch	8	AC	$1,000	$8,000		BARR	Erosion protection
LOW CONTAMINATED ZONE							
Seed	8	AC	$4,000	$32,000		BARR	Plant grass
Hydromulch	8	AC	$1,000	$8,000		BARR	Erosion protection
MISCELLANEOUS							
Re-align Storm Sewer	500	LF	$70	$35,000		BARR	
De-watering/Pre-treatment, Disposal of Water During							
Storm Sewer Work	1	LS	$20,000	$20,000		BARR	Treatment through treatment system ($0.30/gal), discharge to POTW ($0.10/gal)
Abandon Monitoring Wells	4	EA	$3,000	$12,000		BARR	MW-9S,D: MW-7S,D
SUBTOTAL PHYTOREMEDIATION CAPPING:					$584,000		
SITE RESTORATION							
Restore Asphalt							OMC Driveway (South of Site)
Aggregate Subbase	970	CY	$15	$14,550		BARR	
Prepare and Roll Subbase	2,900	SY	$1	$2,900		MEANS	
Asphalt Wear Course	2,900	SY	$8	$23,200		MEANS	
Misc. Grading, Establish Drainage,							
Re-spread Topsoil	1	LS	$10,000	$10,000		BARR	
SUBTOTAL SITE RESTORATION:					$51,000		
ESTIMATED TOTAL FIELD COST				$4,786,000			
ESTIMATED TOTAL FIELD COST, EXCLUDING DISPOSAL				$3,461,000			
Bonds (3%)				$104,000			Does not include Disposal Costs for PAH Remediation Zone material.
Insurance (2%)				$69,000			Does not include Disposal Costs for PAH Remediation Zone material.
Contingencies (15%)				$718,000 [2]			
ESTIMATED TOTAL CONTRACTOR CONSTRUCTION COST:					$5,677,000		

NOTES:
[1] Unit direct cost includes labor, materials, equipment, overhead, and profit.
[2] Calculated as Contingency Multiplier times Estimated Total Field Cos

Table 5-C-21
Waukegan Manufactured Gas & Coke Plant Site
Non-Contractor Capital Costs
Cost Estimate Details

Alternative 3: Removal
Vadose Zone Soil
Option 3B: Disposal
Representative Volume

ITEM	ESTIMATED QUANTITY	UNIT	UNIT DIRECT COST [1]	ITEM TOTAL DIRECT COST		SOURCE	COMMENTS
Remedial Design Investigation							
Soil TCLP Analyses	1	LS	$5,000	$5,000		BARR	
Regulatory Oversight	6	MO	$22,500	$135,000		BARR	
Design	1	LS	$250,000	$250,000		BARR	Includes Work Plan, Design, Construction QAPP, Remedial Action, PHASP, and meetings
Permits/Permitting Assistance	1	LS	$100,000	$100,000			
Engineering Services During Remedial Action	6	MO	$15,000	$90,000		BARR	Includes meetings, design scope changes, etc
Construction Documentation							
Field engineering/construction observatior	6	MO	$25,000	$150,000		BARR	Includes monitoring daily field activities during constructior
Construction documentation report	1	LS	$55,000	$55,000		BARR	Final report - Includes data, statistical clean-up verification analysis, post-remedy soil management plar
Material testing	1	LS	$69,000	$69,000		BARR	2% of construction costs
SUBTOTAL NON-CONTRACTOR COSTS					$854,000		
CONTINGENCY (15%)					$128,000 [2]		
ESTIMATED TOTAL NON-CONTRACTOR CAPITAL COST					$980,000		

NOTES.
[1] Unit price includes labor, materials, and equipment
[2] Calculated as Contingency Multiplier times Subtotal Non-Contractor Direct Costs

Table 5-C-22
Waukegan Manufactured Gas & Coke Plant Site
Operation, Maintenance, and Repair Costs
Cost Estimate Details

Alternative 3: Removal
Vadose Zone Soil
Option 3B: Disposal
Representative Volume

ITEM	ESTIMATED QUANTITY	UNIT	UNIT DIRECT COST [1]	ITEM TOTAL DIRECT COST	FUTURE ITEM TOTAL DIRECT COST	YEAR FUTURE COST OCCURS	PRESENT WORTH OF DIRECT COST [2]	EQUIVALENT ANNUAL COST [2]	SOURCE	COMMENTS
Administration, Inspection, Annual Report	1	LS	$15,000	$15,000			$231,000	$15,000	BARR	
Analysis Review (every 5 years)	1	LS	$11,000			2002	$31,000	$2,000	BARR	
Regulatory Oversight	1	LS	$11,000	$11,000			$169,000	$11,000	BARR	
Maintain Phytoremediation Cover										
Maintenance (first two years)	1	LS	$20,000				$37,188	$2,421	BARR	Includes monthly mowing, spraying for weeds
Maintenance (year two through four)	1	LS	$10,000				$16,865	$1,098	BARR	
Maintenance (after year four)	1	LS	$5,000				$59,133	$3,850	BARR	
Replace Trees (first year)	240	EA	$140	$33,600			$32,001	$2,083	BARR	Replace 20% of trees
Replace Trees (second year)	120	EA	$140	$16,800			$15,238	$992	BARR	Replace 10% of trees
Replace Grass (first year)	4	AC	$4,000	$17,600			$16,762	$1,091	BARR	Re-plant 20% of grass
Watering (first year)	1	LS	$20,000	$20,000			$19,048	$1,240	BARR	
Bi-weekly Inspection (first year)	48	HR	$50	$2,400			$2,286	$149	BARR	Bi-weekly inspection (4-hrs per inspection) for 6 months
Monthly Inspection (after first year)	24	HR	$50	$1,200			$17,304	$1,126	BARR	Weekly inspection (4-hrs per inspection) for 6 months
Folage/Berry Analysis (first two years)	1	LS	$6,000	$6,000			$11,156	$726	BARR	Assumes 10 samples/month at $100/sample for 6 months
Folage/Berry Analysis (after year two)	1	LS	$3,000	$3,000			$40,539	$2,639	BARR	Assumes 5 samples/month at $100/sample for 6 months
SUBTOTAL OM&R COSTS							$699,000	$45,000		
CONTINGENCY (15%)							$105,000	$7,000 [3]		
ESTIMATED TOTAL OPERATION, MAINTENANCE, AND REPAIR COST							$804,000	$52,000		

NOTES:
[1] Unit price includes labor, materials, and equipment.
[2] Present Worth values based on a net discout rate of 5% over 30 years
[3] Calculated as Contingency Multiplier times Subtotal Non-Contractor Direct Costs

Table 5-C-23
Waukegan Manufactured Gas & Coke Plant Site   **Alternative 3: Removal**
Remediation Contractor Capital Costs   **Groundwater**
Cost Estimate Details [1]

ITEM	ESTIMATED QUANTITY	UNIT	UNIT DIRECT COST [2]	ITEM TOTAL DIRECT COST		SOURCE	COMMENTS
GENERAL REQUIREMENTS							
Submittals	1	LS	$20,000	$20,000		BARR	Includes contractor prepartion of submittals which incl. work plans, QA plans, drawings, etc.
Offices	4	MO	$900	$3,600		MEANS	
Mobilization	1	LS	$420,000	$420,000		BARR	General contractor mobe for site work, excavation, water treatment, restoration (10% of cost)
Decontamination and Demobilization	1	LS	$210,000	$210,000		BARR	General contractor demobe for site work, excavation, water treatment, restoration (5% of cost)
Utilities	4	MO	$600	$2,400		BARR	Estimate for FAX, telephone, toilets, heat, electricity, water, trash
Potable Water	4	MO	$800	$3,200		MEANS	
SUBTOTAL GENERAL REQUIREMENTS					$660,000		
SITE WORK							
Dust Control	2	MO	$4,000	$8,000		BARR	Labor and equipment for 2 hrs/day
Ambient Air Monitoring	2	MO	$15,000	$30,000		BARR	Estimate for monitoring from 3 sampling stations for metals, VOCs, particulates.
Vehicle Decontamination	2	MO	$5,000	$10,000		BARR	Cost for steam cleaning and operator for decon of all vehicles and equipment leaving the site
Personal Decontamination	2	MO	$1,900	$3,800		HAZCON	16' X 24' trailer with negative air and 4 showers. Includes transportation.
SUBTOTAL SITE WORK					$52,000		
GROUNDWATER EXTRACTION / INFILTRATION							
Groundwater pump	4	EA	$12,000	$48,000		NEEP SYSTEMS	EconoPump Multi-well jet system, one unit per cell.
Groundwater pump controls	4	EA	$20,000	$80,000			Power supply, controls, and plumbing
Piping - 24" diameter corrugated PEP	1800	LF	$35	$63,000		BARR	Conduit to house piping
Install manholes	10	EA	$2,500	$25,000		BARR	Manholes along conduit
Piping - 1" diameter	54000	LF	$2	$110,000		BARR	1" diameter polyethylene piping between wells and pump, and to reinjection cells.
36" RCP Under Road	260	LF	$75	$20,000		BARR	Casing pipe for well lines. Includes open cut and asphalt restoration
Install monitoring wells	20	WELL	$5,000	$100,000		BARR	Additional groundwater monitoring.
SUBTOTAL GROUNDWATER EXTRACTION / INFILTRATION					$450,000		
WATER TREATMENT - 60 GPM							
Utilities	1	LS	$30,000	$30,000		BARR	$15K power, $10K sewer, $5K water, telephone, etc.
Building for Treatment Equipment	3500	SF	$100	$350,000		MEANS	Warehouse/Storage building at 4000 square feet
HVAC for Treatment Building	3500	SF	$10	$35,000		MEANS	
Electrical for Treatment Building	3500	SF	$9	$32,000		MEANS	
Concrete Slab / Footings	300	CY	$500	$150,000		BARR	Assumes 12" thick slab
System Assembly	1000	HR	$50	$50,000		BARR	
Pipes, Pumps & Equip.	1	LS	$100,000	$100,000		BARR	
Total System Startup	400	HR	$100	$40,000		BARR	
Startup Sampling	100	SMPL	$1,000	$100,000		BARR	
Field Pilot Study							
Equipment - Andco	6	MO	$20,000	$120,000		BARR	Andco equipment rental.
Equipment - Zimpro PACT	6	MO	$25,000	$150,000		BARR	Zimpro equipment rental.
Transportation of Equipment	1	LS	$5,000	$5,000		BARR	Operator 24 hours per week at $60 per hour.
Operation	6	MO	$5,800	$35,000		BARR	Operator 24 hours per week at $60 per hour.
Sampling	430	SMPL	$1,000	$430,000		BARR	14 sampling events, 30 samples per event, plus 6 samples over first 2 weeks
Installation & Startup	200	HR	$100	$20,000		BARR	
Electrochemical Precipitation							
Equipment	1	LS	$160,000	$160,000		ANDCO	Arsenic removal.
Transportation of equipment	1	LS	$5,000	$5,000		ANDCO	
Installation & Startup	1	LS	$20,000	$20,000		BARR	Andco support for start-up.
Activated Sludge with PAC							
PACT System Equipment	1	LS	$900,000	$900,000		ZIMPRO	Phenol, organics, and partial ammonia removal.
Transportation & Installation	1	LS	$290,000	$290,000		ZIMPRO	
SUBTOTAL WATER TREATMENT					$3,000,000		
SUBTOTAL CONTRACTOR DIRECT COST					$4,200,000		
BONDS (3%)					$130,000		
INSURANCE (2%)					$80,000		
CONTINGENCY [3] (15%)					$600,000		
ESTIMATED TOTAL CONTRACTOR CONSTRUCTION COST					$5,000,000		

NOTES:
[1] Includes costs through completion of treatment and disposal
[2] Unit direct cost includes labor, materials, equipment, overhead, and profit
[3] Calculated as Contingency Multiplier times Subtotal Direct Costs

Table 5-C-24
Waukegan Manufactured Gas & Coke Plant Site   **Alternative 3: Removal**
Non-Contractor Capital Costs   **Groundwater**
Cost Estimate Details [1]

ITEM	ESTIMATED QUANTITY	UNIT	UNIT DIRECT COST [2]	ITEM TOTAL DIRECT COST	SOURCE	COMMENTS
Remedial Design Investigation						
Groundwater monitoring wells	1	LS	$200,000	$200,000	BARR	Includes installation of 20 additional monitoring well nests, and geoprobe costs at $1200/day for 2 days
Groundwater sampling	1	LS	$50,000	$50,000	BARR	Sampling and analysis of 22 monitoring well nests and 6 geoprobes
Surface water sampling	1	LS	$100,000	$100,000	BARR	Includes 2 surface water sampling events at $50,000 each
Pilot Study						
Work Plan & Coordination	1	LS	$30,000	$30,000	BARR	Design
Engineering Oversight	6	MO	$10,000	$60,000	BARR	Engineering oversight during pilot study.
Final Report	1	LS	$30,000	$30,000	BARR	Regulatory oversight during construction activities
Remedial Design	1	LS	$250,000	$250,000	BARR	Includes work plan, treatment system and cell design, QA/QC plan, SHSP, and meetings
Bidding/Bidding Administration	1	LS	$30,000	$30,000	BARR	
Permits/Permitting Assistance	1	LS	$50,000	$50,000	BARR	
Regulatory Oversight	4	MO	$22,500	$90,000	BARR	Regulatory oversight during construction activities.
Engineering Services for Remedial Action	4	MO	$15,000	$60,000	BARR	Includes construction meetings, changes to plans and specifications, etc.
Field engineering/construction observation	4	MO	$25,000	$100,000	BARR	Includes monitoring daily field activities for 4 months
H & S Monitoring/Air Monitoring	1	MO	$7,000	$7,000	BARR	Includes health and safety specialist.
Construction documentation report	1	LS	$45,000	$45,000	BARR	Final report
SUBTOTAL NON-CONTRACTOR COSTS				$1,100,000		
CONTINGENCY (15%) [3]				$165,000		
ESTIMATED TOTAL NON-CONTRACTOR CAPITAL COST				$1,270,000		

NOTES.
[1] Includes costs through completion of treatment and disposal
[2] Unit direct cost includes labor, materials, equipment, overhead, and profit
[3] Calculated as Contingency Multiplier times Contractor Subtotal Direct Costs

Table 5-C-25
Waukegan Manufactured Gas & Coke Plant Site   **Alternative 3: Removal**
Operation, Maintenance, and Repair Costs   **Groundwater**
Cost Estimate Details [1]

ITEM	ESTIMATED QUANTITY	UNIT	UNIT DIRECT COST [2]	ANNUAL ITEM TOTAL DIRECT COST	FUTURE ITEM TOTAL DIRECT COST	YEAR FUTURE COST OCCURS	PRESENT WORTH OF DIRECT COST [4]	EQUIVALENT ANNUAL COST [4]	SOURCE	COMMENTS
TREATMENT CELLS										Four treatment cells installed and operated per year.
Sampling, Analysis, Reporting	1	LS	$200,000	$200,000			$900,000	$200,000	BARR	
Wellpoint Installation	120	WELL	$600	$72,000			$310,000	$72,000	MEANS	For one treatment cell: 10 pumping, 20 reinjection wells.
Additional Piping - 1" diameter	24000	LF	$2	$48,000			$210,000	$48,000	BARR	1" diameter polyethylene required for moving the treatment ce
Repair, Maintenance	1	LS	$80,000	$80,000			$350,000	$80,000	BARR	Well and pump maintenance.
SUBTOTAL CELL OM&R COSTS							$1,800,000	$400,000		
Engineering Oversight	400	HR	$100	$40,000			$170,000	$40,000		
WATER TREATMENT										
Heating and Cooling of Treatment Building	1	LS	$40,000	$40,000			$170,000	$40,000		
ELECTROCHEMICAL PRECIPITATION										
Annual Report	1	LS	$10,000	$10,000			$43,000	$10,000		Arsenic removal.
Sampling, Analysis, Reporting	30	SAMPLE	$500	$15,000			$65,000	$15,000		
Residual Transport and Disposal	20	TON	$100	$2,000			$9,000	$2,000	BARR	Disposal of Sludge in a Subtitle D Landfill
Labor for Operation	3000	HR	$50	$150,000			$650,000	$150,000		Operator assumed 8 hours per day, 7 days per week.
Power and Iron Costs	32000	1000 GAL	$0.33	$11,000			$48,000	$11,000		Cost per 1000 gallons treated.
PACT SYSTEM										
Annual Report	1	LS	$15,000	$15,000			$65,000	$15,000		Phenol, organics, and partial ammonia removal.
Sampling, Analysis, Reporting	30	SAMPLE	$600	$18,000			$78,000	$18,000		
Residual Transport and Disposal	150	TON	$100	$15,000			$65,000	$15,000	BARR	Disposal of Sludge in a Subtitle D Landfill
Labor for Operation Optimization	3000	HR	$50	$150,000			$650,000	$150,000		Operator assumed 8 hours per day, 7 days per week.
Power and Chemical Costs	365	DAY	$220	$80,000			$350,000	$80,000		
Groundwater Monitoring	160	SAMPLE	$1,000	$160,000			$690,000	$160,000		12 well nests, 3 depths for each nest, sampled quarterly
SUBTOTAL WATER TREATMENT OM&R COSTS							$3,100,000	$710,000		
TREATMENT EQUIPMENT										
Pipes, Pumps, and Equipment	1	LS	$10,000	$10,000			$43,000	$10,000	BARR	10% of equipment capital cost
Electrochemical Precipitation Equipment	1	LS	$32,000	$32,000			$140,000	$32,000	BARR	20% of equipment capital cost
PACT System Equipment	1	LS	$36,000	$36,000			$160,000	$36,000	BARR	4% of equipment capital cost
SUBTOTAL TREATMENT EQUIPMENT M&R COSTS							$300,000	$78,000		
MONITORED NATURAL ATTENUATION										12 well nests, 3 depths for each nest, and 4 surface
Groundwater Monitoring	160	SAMPLE	$1,000	$160,000			$2,500,000	$160,000		water locations sampled quarterly
Data Evaluation/Modeling	1	LS	$10,000	$10,000			$150,000	$10,000	BARR	
Admin, Inspection, Annual Report	1	LS	$50,000	$50,000			$770,000	$50,000	BARR	
Five Year Review	1	LS	$60,000			2003	$60,000	$3,900		
Regulatory Oversight	1	LS	$10,000	$10,000			$150,000	$10,000	BARR	
SUBTOTAL MONITORED NATURAL ATTENUATION							$3,600,000	$230,000		
SUBTOTAL OM&R COSTS							$8,800,000	$1,400,000		
CONTINGENCY [3] (15%)							$1,320,000	$210,000		
ESTIMATED TOTAL OM&R COSTS							$10,100,000	$1,600,000		

NOTES:
[1] Includes costs through completion of treatment and disposal
[2] Unit direct cost includes labor, materials, equipment, overhead, and profit.
[3] Calculated as Contingency Multiplier times Subtotal Direct Costs
[4] Present Worth values based on a net discount rate of 5% over 5 years

Table 5-C-26
Waukegan Manufactured Gas & Coke Plant Site
Remediation Contractor Capital Costs
Cost Estimate Details

Alternative 4: Removal of Vadose Zone Soil
Vadose Zone Soil
Option 4: Treatment
Representative Volume

ITEM	ESTIMATED QUANTITY	UNIT	UNIT DIRECT COST (1)	ITEM TOTAL DIRECT COST		SOURCE	COMMENTS
GENERAL REQUIREMENTS							
Submittals	1	LS	$20,000	$20,000		BARR	Includes contractor preparation of submittals which include work plans, QA plans, drawings, etc
Office	10	MO	$900	$9,000		MEANS	Rental of 2 - 50' x 12' trailer w/ AC
Mobilization	1	LS	$1,122,100	$1,122,100		BARR	10% of construction costs, does not include disposal
Demobilization and Decontamination	1	LS	$561,050	$561,050		BARR	5% of construction costs, does not inclued disposal
Utilities	10	MO	$600	$6,000		BARR	Estimate for FAX, telephone, toilets, heat, electricity, water, trash
Potable Water	10	MO	$800	$8,000		BARR	Includes delivered bottled water at 150 ga/week and rental of two coolers
SUBTOTAL GENERAL REQUIREMENTS:					$1,726,000		
SITE WORK							
Connect Utilities	1	LS	$5,000	$5,000		BARR	Includes connection of telephone and electricity to offices
Runon/runoff Control	1	LS	$10,000	$10,000		BARR	Install berms, silt fence, drainage ditches
Clear and Grub	22.0	AC	$4,500.00	$99,000		MEANS	Clear & Grub brush, including stumps
Dust Control	10	MO	$4,000	$40,000		BARR	Labor and equipment for 2 hrs/day
Ambient Air Monitoring	10	MO	$15,000	$150,000		BARR	Estimate for monitoring from 3 sampling stations for metals, VOCs, particulates
Vehicle Decontamination Pad	10	LS	$4,000	$40,000		BARR	Construct a lined treatment decon area.
Vehicle Decontamination	10	MO	$5,000	$50,000		BARR	Cost for steam cleaning and operator for decon of all vehicles and equipment leaving the site
Personal Decontamination	10	MO	$1,900	$19,000		HAZCON	18'x24' trailer with negative air and 4 showers. Includes transportation
Water Storage Tanks	10	MO	$5,000	$50,000		BARR	Assume 2 Baker tanks
Access Improvements, Relocate Fence	1	LS	$10,000	$10,000		BARR	Site Improvements
SUBTOTAL SITE WORK					$473,000		
EXCAVATION, TREATMENT, DISPOSAL, AND BACKFILL							
PAH REMEDIATION ZONE							
Set Up Processing and Stockpile Area	1	LS	$100,000	$100,000		BARR	Concrete pad for soil processing equipment, asphalt pad, concrete walls for soil staging
Strip and Stockpile Overburden	12,100	CY	$3	$36,300		BARR	Assume 6" overburden in excavation area
Remove Existing Asphalt	7,200	SY	$5	$36,000		MEANS	OMC Driveway (South of Site)
Asphalt Disposal	1,800	CY	$30	$54,000		BARR	Recycle
Excavate Soil, Separate PAH Material, and Segregate Debris	14,300	CY	$20	$286,000		BARR	7,100 CY of tar & oily soil, 7,200 cy of overburden
Soil Mixing and Loading	16,000	Ton	$40	$640,000		BARR	Screening to segregate debris and mixing with coal (50% by wt) and other on-site soil to render non-hazardou
Sampling and Testing Processed Material	16,000	Ton	$10	$160,000		BARR	TCLP analysis
Load and Haul Processed Material	16,000	Ton	$60	$960,000		Kipin	
Thermal Treatment	16,000	Ton	$50	$800,000		Kipin	
Clean Debris	2,100	Ton	$20	$42,000		BARR	Debris consists of bricks, rebar, concerete, timber, and pipe; assume 10% debris by weigh
Load and Haul Debris to Local Landfill	2,100	Ton	$10	$21,000		BARR	
Debris Disposal at Landfill	2,100	Ton	$20	$42,000		BARR	
ARSENIC REMEDIATON ZONE							
Excavate Soil, Seperate Material Requiring Stabilization, and Segregate Debris	83,000	CY	$20	$1,660,000		BARR	
Load and Haul Arsenic Material	124,600	Ton	$33	$4,111,800		PDC	
Disposal at RCRA Subtitle C Landfill (requiring stabilization)	5,000	Ton	$100	$500,000		PDC	Includes stabilization of arsenic and disposal in Peoria, IL
Disposal at RCRA Subtitle C Landfill (no stabilization)	119,600	Ton	$40	$4,784,000		PDC	
Clean Debris	12,500	Ton	$20	$250,000		BARR	Debris consists of bricks, rebar, concrete, timber, and pipe; assume 10% debris by weigh
Load and Haul Debris to Local Landfill	12,500	Ton	$10	$125,000		BARR	
Debris Disposal at Landfill	12,500	Ton	$20	$250,000		BARR	
Dewatering, Pre-Treatment, and Disposal of Water During Excavation	1,750	1,000 Gal	$400	$700,000		BARR	Treatment through treatment system ($0.30/gal), discharge to POTW ($0.10/gal
BACKFILL							
Load, Haul, Backfill, and Compact Soil from Designated Stockpile	5,000	CY	$5	$25,000		BARR	
Backfill from Off-Site Source	85,100	CY	$12	$1,021,200		BARR	Includes $10/cy for material and delivery to site and $2/cy for installation
SUBTOTAL EXCAVATION, TREATMENT, DISPOSAL, AND BACKFILL:					$16,604,000		

Table 5-C-26 (continued)
Waukegan Manufactured Gas & Coke Plant Site
Remediation Contractor Capital Costs
Cost Estimate Details

Alternative 4: Removal of Vadose Zone Soil
Vadose Zone Soil
Option 4: Treatment
Representative Volume

ITEM	ESTIMATED QUANTITY	UNIT	UNIT DIRECT COST [1]	ITEM TOTAL DIRECT COST		SOURCE	COMMENTS
MISCELLANEOUS							
Re-align Storm Sewer	500	LF	$70	$35,000		BARR	Includes restoration of lawn and parking lot, and manholes
De-watering/Pre-treatment, Disposal of Water During							
Storm Sewer Work	1	LS	$20,000	$20,000		BARR	Treatment through treatment system ($0.30/gal), discharge to POTW ($0.10/gal)
Abandon Monitoring Wells	4	EA	$3,000	$12,000		BARR	MW-9S,D: MW-7S,D
SUBTOTAL MISCELLANEOUS:				$67,000			
SITE RESTORATION							
Restore Asphalt							OMC Driveway (South of Site)
Aggregate Subbase	970	CY	$15	$14,550		BARR	
Prepare and Roll Subbase	2,900	SY	$1	$2,900		MEANS	
Asphalt Wear Course	2,900	SY	$8	$23,200		MEANS	
Misc. Grading, Establish Drainage,							
Re-spread Topsoil	1	LS	$10,000	$10,000		BARR	
Turf Establisment, Temporary Erosion Control	22	AC	$5,000	$110,000		BARR	
SUBTOTAL SITE RESTORATION:				$161,000			
ESTIMATED TOTAL FIELD COST				$19,031,000			
ESTIMATED TOTAL FIELD COST, EXCLUDING DISPOSAL				$12,947,000			
Bonds (3%)				$388,000			Does not include Disposal Costs for PAH Remediation Zone material.
Insurance (2%)				$259,000			Does not include Disposal Costs for PAH Remediation Zone material.
Contingencies (15%)				$2,855,000	[2]		
ESTIMATED TOTAL CONTRACTOR CONSTRUCTION COST:					$22,533,000		

NOTES:
[1] Unit direct cost includes labor, materials, equipment, overhead, and profit.
[2] Calculated as Contingency Multiplier times Estimated Total Field Cost

Table 5-C-27
Waukegan Manufactured Gas & Coke Plant Site
Non-Contractor Capital Costs
Cost Estimate Details

Alternative 4: Removal of Vadose Zone Soil
Vadose Zone Soil
Option 4: Treatment
Representative Volume

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ITEM	ESTIMATED QUANTITY	UNIT	UNIT DIRECT COST [1]	ITEM TOTAL DIRECT COST		SOURCE	COMMENTS
Remedial Design Investigation							
Arsenic Stabilization Treatability Study	1	LS	$30,000	$30,000		BARR	
Soil TCLP Analyses	1	LS	$5,000	$5,000		BARR	
Regulatory Oversight	10	MO	$22,500	$225,000		BARR	
Design	1	LS	$250,000	$250,000		BARR	Includes Work Plan, design, construction QAPP, Remedial Action Plan, PHASP, and meetings
Permits/Permitting Assistance	1	LS	$100,000	$100,000			
Engineering Services During Remedial Action	10	MO	$15,000	$150,000		BARR	Includes meetings, design scope changes, etc
Construction Documentation							
Field engineering/construction observation	10	MO	$25,000	$250,000		BARR	Includes monitoring daily field activities during construction
Construction documentation report	1	LS	$55,000	$55,000		BARR	Final report - includes data, statistical cleanup verification analysis, post-remedy soil management plan
Material testing	1	LS	$259,000	$259,000		BARR	2% of construction costs
SUBTOTAL NON-CONTRACTOR COSTS					$1,324,000		
CONTINGENCY (15%)					$199,000 [2]		
ESTIMATED TOTAL NON-CONTRACTOR CAPITAL COST:					$1,520,000		

NOTES:
[1] Unit price includes labor, materials, and equipment
[2] Calculated as Contingency Multiplier times Subtotal Non-Contractor Direct Costs

Table 5-C-28
Waukegan Manufactured Gas & Coke Plant Site
Operation, Maintenance, and Repair Costs
Cost Estimate Details

Alternative 4: Removal of Vadose Zone Soil
Vadose Zone Soil
Option 4: Treatment
Representative Volume

ITEM	ESTIMATED QUANTITY	UNIT	UNIT DIRECT COST [1]	ANNUAL ITEM TOTAL DIRECT COST	FUTURE ITEM TOTAL DIRECT COST	YEAR FUTURE COST OCCURS	PRESENT WORTH OF DIRECT COST[2]	EQUIVALENT ANNUAL COST[2]	SOURCE	COMMENTS
Administration, Inspection, Annual Report	1	LS	$15,000	$15,000			$231,000	$15,000	BARR	
Analysis Review (every 5 years)	1	LS	$11,000			2002	$31,000	$2,000	BARR	
Regulatory Oversight	1	LS	$11,000	$11,000			$169,000	$11,000	BARR	
SUBTOTAL OM&R COSTS							$431,000	$28,000		
CONTINGENCY (15%)							$65,000	$4,000 [3]		
ESTIMATED TOTAL OPERATION, MAINTENANCE, AND REPAIR COST							$496,000	$32,000		

NOTES
[1] Unit price includes labor, materials, and equipment
[2] Present Worth values based on a net discout rate of 5% over 30 years
[3] Calculated as Contingency Multiplier times Subtotal Non-Contractor Direct Costs

Table 5-C-29
Waukegan Manufactured Gas & Coke Plant Site
Remediation Contractor Capital Costs
Cost Estimate Details [1]

Alternative 4: Aquifer Restoration
Groundwater

ITEM	ESTIMATED QUANTITY	UNIT	UNIT DIRECT COST [2]	ITEM TOTAL DIRECT COST		SOURCE	COMMENTS
GENERAL REQUIREMENTS							
Submittals	1	LS	$20,000	$20,000		BARR	Includes contractor preparation of submittals which include work plans, QA plans, drawings, etc
Office	4	MO	$900	$3,600		MEANS	Rental of 2 - 50' x 12' trailer w/ AC
Mobilization	1	LS	$1,300,000	$1,300,000		BARR	10% of construction costs
Demobilization and Decontamination	1	LS	$670,000	$670,000		BARR	5% of construction costs
Utilities	4	MO	$600	$2,400		BARR	Estimate for FAX, telephone, toilets, heat, electricity, water, trash
Potable Water	4	MO	$800	$3,200		BARR	Includes delivered bottled water at 150 ga/week and rental of two coolers.
SUBTOTAL GENERAL REQUIREMENTS				$2,000,000			
SITE WORK							
Dust Control	4	MO	$4,000	$16,000		BARR	Labor and equipment for 2 hrs/day
Ambient Air Monitoring	4	MO	$15,000	$60,000		BARR	Estimate for monitoring from 3 sampling stations for metals, VOCs, particulates.
Vehicle Decontamination	2	MO	$5,000	$10,000		BARR	Cost for steam cleaning and operator for decon of all vehicles and equipment leaving the site.
Personal Decontamination	2	MO	$1,900	$3,800		HAZCON	18'x24' trailer with negative air and 4 showers. Includes transportation.
SUBTOTAL SITE WORK				$90,000			
GROUNDWATER EXTRACTION AND DISCHARGE							
Groundwater Extraction Wells/Pumps/Controls	40	WELL	$25,000	$1,000,000		BARR	
Piping - 24" diameter corrugated PEP	1800	LF	$35	$63,000		BARR	Conduit to house piping
Install manholes	10	EA	$2,500	$25,000		BARR	Manholes along conduit
Piping - 2" diameter	4500	LF	$4	$18,000		BARR	2" diameter polyethylene piping between wells and pump, and to reinjection cells.
36" RCP Under Road	260	LF	$75	$20,000		BARR	Casing pipe for well lines. Includes open cut and asphalt restoration
Install monitoring wells	20	WELL	$5,000	$100,000		BARR	
Install sewage lift station	1	LS	$54,000	$54,000		MEANS	Prefabricated steel, concrete, or fiberglass, 200 GPM.
Discharge Piping - 8" diameter	1650	LF	$10	$17,000		MEANS	8" diameter PVC piping.
Pipe Fittings - 8" diameter	165	EA	$95	$16,000		MEANS	8" diameter PVC pipe fittings.
Excavation, Backfill, Compaction for Discharge Pipe	5200	CY	$20	$100,000		BARR	Includes excavation, backfill, and compaction.
SUBTOTAL GROUNDWATER EXTRACTION AND DISCHARGE				$1,400,000			

NOTES:
[1] Includes costs through completion of treatment and disposal
[2] Unit direct cost includes labor, materials, equipment, overhead, and profit
[3] Calculated as Contingency Multiplier times Contractor Subtotal Direct Costs

Table 5-C-29 (continued)
Waukegan Manufactured Gas & Coke Plant Site   **Alternative 4: Aquifer Restoration**
Remediation Contractor Capital Costs   **Groundwater**
Cost Estimate Details [1]

ITEM	ESTIMATED QUANTITY	UNIT	UNIT DIRECT COST [2]	ITEM TOTAL DIRECT COST	SOURCE	COMMENTS
WATER TREATMENT - 200 GPM						
Utilities	1	LS	$30,000	$30,000	BARR	$15K power, $10K sewer, $5K water, telephone, etc.
Building for Treatment Equipment	8000	SF	$100	$800,000	BARR	
HVAC for Treatment Building	8000	SF	$10	$80,000	MEANS	
Electrical for Treatment Building	8000	SF	$9	$72,000	MEANS	
Concrete Slab / Footings	1100	CY	$500	$550,000	BARR	Assumes 12" thick slab
System Assembly	2000	HR	$50	$100,000	BARR	
Pipes, Pumps & Equipment	1	LS	$200,000	$200,000	BARR	
Total System Startup	1200	HR	$100	$120,000	BARR	
Startup Sampling	300	SMPL	$1,000	$300,000	BARR	
Field Pilot Study						
Equipment - Andco	6	MO	$20,000	$120,000	ANDCO	Andco equipment rental.
Equipment - Zimpro PACT	6	MO	$25,000	$150,000	ZIMPRO	Zimpro equipment rental.
Equipment - UV/Peroxide	6	MO	$40,000	$240,000	BARR	UV/Peroxide equipment rental.
Transportation of Equipment	1	LS	$5,000	$5,000	BARR	
Operation	6	MO	$5,800	$35,000	BARR	Operator 24 hours per week at $60 per hour.
Sampling	430	SMPL	$1,000	$430,000	BARR	14 sampling events, 30 samples per event, plus 6 samples over first 2 weeks.
Installation & Startup	200	HR	$100	$20,000	BARR	
Electrochemical Precipitation						
Equipment	1	LS	$210,000	$210,000	ANDCO	Arsenic removal.
Transportation of equipment	1	LS	$5,000	$5,000	ANDCO	
Installation & Startup	1	LS	$20,000	$20,000	BARR	Andco support for start-up.
Phenol/Organics Removal - biological						
PACT System Equipment	1	LS	$1,000,000	$1,000,000	ZIMPRO	Phenol and organics removal.
Transportation & Installation	1	LS	$340,000	$340,000	ZIMPRO	
Ammonia Removal - biological						
PACT System Equipment	1	LS	$2,500,000	$2,500,000	ZIMPRO	Ammonia nitrification and denitrification.
Transportation & Installation	1	LS	$575,000	$575,000	ZIMPRO	
UV/Peroxide Treatment System						
Equipment - 2 stage	1	LS	$4,000,000	$4,000,000	BARR	Cyanide removal to meet NSSD discharge requirements.
Transportation & Installation	1	LS	$500,000	$500,000	BARR	

SUBTOTAL WATER TREATMENT	$12,000,000
SUBTOTAL CONTRACTOR DIRECT COST	$15,000,000
BONDS (3%)	$450,000
INSURANCE (2%)	$300,000
CONTINGENCY [3] (15%)	$2,300,000
ESTIMATED TOTAL CONTRACTOR CONSTRUCTION COST	$18,000,000

NOTES:
[1] Includes costs through completion of treatment and disposal
[2] Unit direct cost includes labor, materials, equipment, overhead, and profit
[3] Calculated as Contingency Multiplier times Contractor Subtotal Direct Costs

Table 5-C-30
Waukegan Manufactured Gas & Coke Plant Site   **Alternative 4: Aquifer Restoration**
Non-Contractor Capital Costs   **Groundwater**
Cost Estimate Details [1]

ITEM	ESTIMATED QUANTITY	UNIT	UNIT DIRECT COST [2]	ITEM TOTAL DIRECT COST		SOURCE	COMMENTS
Remedial Design Investigation							
Groundwater monitoring wells	1	LS	$200,000	$200,000		BARR	Includes installation of 20 additional monitoring well nests, and geoprobe costs at $1200/day for 2
Groundwater sampling	1	LS	$50,000	$50,000		BARR	Sampling and analysis of 22 monitoring well nests and 6 geoprobes
Surface water sampling	1	LS	$100,000	$100,000		BARR	Includes 2 surface water sampling events at $50,000 each
Pilot Study							
Work Plan & Coordination	1	LS	$30,000	$30,000		BARR	Design.
Engineering Oversight	6	MO	$10,000	$60,000		BARR	Engineering oversight during pilot study.
Final Report	1	LS	$30,000	$30,000		BARR	Regulatory oversight during construction activities.
Design	1	LS	$390,000	$390,000		BARR	Includes work plan, treatment system design, QA/QC plan, SHSP, and meetings
Bidding/Bidding Administration	1	LS	$30,000	$30,000		BARR	
Permits/Permitting Assistance	1	LS	$50,000	$50,000		BARR	
Regulatory Oversight	4	MO	$22,500	$90,000		BARR	Regulatory oversight during preconstruction and construction activities.
Engineering Services for Remedial Action	4	MO	$15,000	$60,000		BARR	Includes construction meetings, changes to plans and specifications, etc.
Field engineering/construction observation	4	MO	$25,000	$100,000		BARR	Includes monitoring daily field activities for 4 months.
H & S Monitoring/Air Monitoring	1	MO	$7,000	$7,000		BARR	Includes health and safety specialist.
Construction documentation report	1	LS	$45,000	$45,000		BARR	Final report
SUBTOTAL NON-CONTRACTOR COSTS					$1,240,000		
CONTINGENCY (15%) [3]					$190,000		
ESTIMATED TOTAL NON-CONTRACTOR CAPITAL COST					$1,430,000		

NOTES:
[1] Includes costs through completion of treatment and disposal
[2] Unit direct cost includes labor, materials, equipment, overhead, and profit
[3] Calculated as Contingency Multiplier times Contractor Subtotal Direct Costs

Table 5-C-31
Waukegan Manufactured Gas & Coke Plant Site   Alternative 4: Aquifer Restoration
Operation, Maintenance, and Repair Costs   Groundwater
Cost Estimate Details [1]

ITEM	ESTIMATED QUANTITY	UNIT	UNIT DIRECT COST [2]	ANNUAL ITEM TOTAL DIRECT COST	FUTURE ITEM TOTAL DIRECT COST	YEAR FUTURE COST OCCURS	PRESENT WORTH OF DIRECT COST [4]	EQUIVALENT ANNUAL COST [4]	SOURCE	COMMENTS
GENERAL										
Admin, Inspection and Annual Reporting	1	LS	$50,000	$50,000			$910,000	$50,000	BARR	
Well Repair/ Maintenance	1	LS	$40,000	$40,000			$730,000	$40,000	BARR	
SUBTOTAL GENERAL OM&R COSTS							$1,600,000	$90,000		
Engineering Oversight	600	HR	$100	$60,000			$1,100,000	$60,000	BARR	
WATER TREATMENT										
Heating and Cooling of Treatment Building	1	LS	$60,000	$60,000			$1,100,000	$60,000		
ELECTROCHEMICAL PRECIPITATION										Arsenic removal.
Annual Report	1	LS	$10,000	$10,000			$180,000	$10,000		
Sampling, Analysis, Reporting	30	SAMPLE	$500	$15,000			$270,000	$15,000		
Residual Transport and Disposal	50	TON	$100	$5,000			$91,000	$5,000	BARR	Disposal of Sludge in a Subtitle D Landfill
Labor for Operation	3000	HR	$50	$150,000			$2,700,000	$150,000		Operator assumed 8 hours per day, 7 days per week.
Power and Iron Costs	105000	1000 GAL	$0.33	$35,000			$640,000	$35,000		Cost per 1000 gallons treated.
PACT SYSTEM - PHENOL/ORGANICS REMOVAL										Phenol and organics removal.
Annual Report	1	LS	$10,000	$10,000			$180,000	$10,000		
Sampling, Analysis, Reporting	30	SAMPLE	$500	$15,000			$270,000	$15,000		
Residual Transport and Disposal	250	TON	$100	$25,000			$460,000	$25,000	BARR	Disposal of Sludge in a Subtitle D Landfill
Labor for Operation Optimization	3000	HR	$50	$150,000			$2,700,000	$150,000		Operator assumed 8 hours per day, 7 days per week.
Power and Chemical Costs	365	DAY	$314	$110,000			$2,000,000	$110,000		
PACT SYSTEM - AMMONIA REMOVAL										Ammonia nitrification and denitrification.
Annual Report	1	LS	$10,000	$10,000			$180,000	$10,000		
Sampling, Analysis, Reporting	30	SAMPLE	$500	$15,000			$270,000	$15,000		
Residual Transport and Disposal	250	TON	$100	$25,000			$460,000	$25,000	BARR	Disposal of Sludge in a Subtitle D Landfill
Labor for Operation Optimization	3000	HR	$50	$150,000			$2,700,000	$150,000		Operator assumed 8 hours per day, 7 days per week.
Power and Chemical Costs	365	DAY	$545	$200,000			$3,700,000	$200,000		
Carbon Source Addition for Denitrification	365	DAY	$330	$120,000			$2,200,000	$120,000		
UV/PEROXIDE - POLISHING STEP										Cyanide removal to meet NSSD discharge requirements.
Annual Report	1	LS	$10,000	$10,000			$180,000	$10,000		
Sampling, Analysis, Reporting	30	SAMPLE	$500	$15,000			$270,000	$15,000		
Power and Chemical Costs	365	DAY	$500	$180,000			$3,300,000	$180,000		
Discharge to NSSD	105000	1000 GAL	$4	$420,000			$7,700,000	$420,000		Cost per 1000 gallons treated (standard rate is $100/1000 gallons).
Groundwater Monitoring	160	SAMPLE	$1,000	$160,000			$2,900,000	$160,000		
SUBTOTAL WATER TREATMENT OM&R COSTS							$36,000,000	$2,000,000		
TREATMENT EQUIPMENT										
Replace Wells (every 10 years)	40	WELL	$25,000	$1,000,000		2008, 2018,2028, ;	$1,400,000	$91,000	BARR	
Pipes, Pumps, and Equipment	1	LS	$20,000	$20,000			$370,000	$20,000	BARR	10% of equipment capital cost
Electrochemical Precipitation Equipment	1	LS	$42,000	$42,000			$770,000	$42,000	BARR	20% of equipment capital cost
PACT System Equipment	1	LS	$40,000	$40,000			$730,000	$40,000	BARR	4% of equipment capital cost
PACT System Equipment - Ammonia Removal	1	LS	$100,000	$100,000			$1,800,000	$100,000	BARR	4% of equipment capital cost
UV/Peroxide Equipment	1	LS	$320,000	$320,000			$5,800,000	$320,000	BARR	8% of equipment capital cost
SUBTOTAL TREATMENT EQUIPMENT M&R COSTS							$11,000,000	$610,000		
SUBTOTAL OM&R COSTS							$49,000,000	$2,700,000		
CONTINGENCY [3] (15%)							$7,400,000	$410,000		
ESTIMATED TOTAL OM&R COSTS							$56,000,000	$3,100,000		

NOTES:
[1] Includes costs through completion of treatment and disposal.
[2] Unit direct cost includes labor, materials, equipment, overhead, and profit.
[3] Calculated as Contingency Multiplier times Subtotal Direct Costs.
[4] Present Worth values based on a net discount rate of 5% over 50 years.

Table 5-C-32
Waukegan Manufactured Gas & Coke Plant Site
Remediation Contractor Capital Costs
Cost Estimate Details

Alternative 2: Containment
Vadose Zone Soil
Option 2A: Treatment
High Volume

ITEM	ESTIMATED QUANTITY	UNIT	UNIT DIRECT COST [1]	ITEM TOTAL DIRECT COST		SOURCE	COMMENTS
GENERAL REQUIREMENTS							
Submittals	1	LS	$20,000	$20,000		BARR	Includes contractor preparation of submittals which include work plans, QA plans, drawings, etc
Office	7	MO	$900	$6,300		MEANS	Rental of 2 - 50' x 12' trailer w/ AC
Mobilization	1	LS	$993,500	$993,500		BARR	10% of construction costs, does not include disposal
Demobilization and Decontamination	1	LS	$496,750	$496,750		BARR	5% of construction costs, does not inclued disposal
Utilities	7	MO	$600	$4,200		BARR	Estimate for FAX, telephone, toilets, heat, electricity, water, trash
Potable Water	7	MO	$800	$5,600		BARR	Includes delivered bottled water at 150 ga/week and rental of two coolers
SUBTOTAL GENERAL REQUIREMENTS:					$1,526,000		
SITE WORK							
Connect Utilities	1	LS	$5,000	$5,000		BARR	Includes connection of telephone and electricity to offices
Runon/runoff Control	1	LS	$10,000	$10,000		BARR	Install berms, silt fence, drainage ditches
Clear, Grub, and Subgrade Preparation	13.2	AC	$4,500.00	$59,421		MEANS	Clear & Grub brush, including stumps
Dust Control	7	MO	$4,000	$28,000		BARR	Labor and equipment for 2 hrs/day
Ambient Air Monitoring	7	MO	$15,000	$105,000		BARR	Estimate for monitoring from 3 sampling stations for metals, VOCs, particulates
Vehicle Decontamination Pad	7	LS	$4,000	$28,000		BARR	Construct a lined treatment decon area.
Vehicle Decontamination	7	MO	$5,000	$35,000		BARR	Cost for steam cleaning and operator for decon of all vehicles and equipment leaving the site
Personal Decontamination	7	MO	$1,900	$13,300		HAZCON	18'x24' trailer with negative air and 4 showers. Includes transportation
Water Storage Tanks	7	MO	$5,000	$35,000		BARR	Assume 2 Baker tanks
Access Improvements, Relocate Fence	1	LS	$10,000	$10,000		BARR	Site Improvements
SUBTOTAL SITE WORK:					$329,000		
EXCAVATION, TREATMENT, DISPOSAL, AND BACKFILL							
PAH REMEDIATION ZONE							
Set Up Processing and Stockpile Area	1	LS	$100,000	$100,000		BARR	Concrete pad for soil processing equipment, asphalt pad, concrete walls for soil staging
Strip and Stockpile Overburden	10,700	CY	$3	$32,100		BARR	Assume 6" Overburden Across Site
Remove Existing Asphalt	7,200	SY	$5	$36,000		MEANS	OMC Driveway (South of Site)
Asphalt Disposal	1,800	CY	$30	$54,000		BARR	Recycle
Excavate Soil, Separate PAH Material, and Segregate Debris	29,300	CY	$20	$586,000		BARR	14,900 CY of tar & oily soil, 14,400 cy of overburden
Soil Mixing and Loading	33,500	Ton	$40	$1,340,000		BARR	Screening to segregate debris and mixing with coal (50% by wt) and other on-site soil to render non-hazardous
Sampling and Testing Processed Material	33,500	Ton	$10	$335,000		BARR	TCLP analysis
Load and Haul Processed Material to Power Plant	33,500	Ton	$60	$2,010,000		KIPIN	Illinois Power, Baldwin power plant near East St. Louis
Thermal Treatment	33,500	Ton	$50	$1,675,000		KIPIN	
Clean Debris	4,400	Ton	$20	$88,000		BARR	Debris consists of bricks, rebar, concerete,timber, and pipe; assume 10% debris by weigh
Load and Haul Debris to Local Landfill	4,400	Ton	$10	$44,000		BARR	
Debris Disposal at Landfill	4,400	Ton	$20	$88,000		BARR	
Dewatering, Pre-Treatment, and Disposal of Water During Excavation	2,800	1,000 Gal	$400	$1,120,000		BARR	Treatment through treatment system ($0.30/gal), discharge to POTW ($0.10/gal)
ARSENIC REMEDIATON ZONE							
Excavate Soil and Segregate Debris	7,200	CY	$20	$144,000		BARR	
Soil Stabilization and Stockpiling	10,800	Ton	$80	$864,000		BARR	
Sampling and Testing Processed Material	10,800	Ton	$10	$108,000		BARR	TCLP analysis
BACKFILL							
Backfill and Compact Stabilized Material	8,700	CY	$15	$130,500		BARR	
Load, Haul, Backfill, and Compact Soil from Designated Stockpile and Overburden	19,400	CY	$5	$97,000		BARR	
Backfill from Off-Site Source	9,900	CY	$12	$118,800		BARR	Includes $10/cy for material and delivery to site and $2/cy for installation
SUBTOTAL EXCAVATION, TREATMENT, DISPOSAL, AND BACKFILL:					$8,970,000		

Table 5-C-32 (continued)
Waukegan Manufactured Gas & Coke Plant Site
Remediation Contractor Capital Costs
Cost Estimate Details

Alternative 2: Containment
Vadose Zone Soil
Option 2A: Treatment
High Volume

ITEM	ESTIMATED QUANTITY	UNIT	UNIT DIRECT COST [1]	ITEM TOTAL DIRECT COST	SOURCE	COMMENTS
ASPHALT CAPPING						
CAP CONSTRUCTION						
Import Fill for Grading/Shaping	21,300	CY	$12	$255,600	BARR	12" cover over cap area
60-mil HDPE Geomembrane	575,200	SF	$0.85	$488,900	BARR	Reduce Permeability
Protective Cover	21,300	CY	$15	$319,500	BARR	12" Granular Drainage Material Over HDPE
Aggregate Subbase	21,300	CY	$15	$319,500	BARR	12" Thick
Prepare and Roll Subbase	63,900	SY	$1	$63,900	MEANS	
Asphalt Wear Course	63,900	SY	$8	$511,200	MEANS	3" Thick
Asphalt Berm Curb	3,900	LF	$2	$7,800	MEANS	
MISCELLANEOUS						
Re-align Storm Sewer	500	LF	$70	$35,000	BARR	Includes restoration of lawn, parking lot, and manholes
De-watering/Pre-treatment, Disposal of Water During						
Storm Sewer Work	1	LS	$20,000	$20,000	BARR	Treatment through treatment system ($0.30/gal), discharge to POTW ($0.10/gal)
Abandon Monitoring Wells	4	EA	$3,000	$12,000	BARR	MW-9S,D: MW-7S,D
SUBTOTAL ASPHALT CAPPING:				$2,033,000		
STORMWATER DETENTION POND AND APPURTENANCES						
Catch Basins	6	EA	$2,000	$12,000	BARR	1 Catch Basin/2 acres of cap
Piping Between Catch Basins	2,000	LF	$50	$100,000	BARR	
Manholes	2	EA	$2,500	$5,000	BARR	
Excavation	24,000	CY	$10	$240,000	BARR	
HDPE Liner	152,500	SF	$0.85	$129,625	BARR	
Backfill	2,800	CY	$5	$14,000	BARR	On-site material
Outlet Structure	1	EA	$10,000	$10,000	BARR	
Outlet Pipe	150	LF	$75	$11,250	BARR	Outlet to harbor
SUBTOTAL STORMWATER DETENTION POND AND APPURTENANCES:				$522,000		
SITE RESTORATION						
Restore Asphalt						OMC Driveway (South of Site)
Aggregate Subbase	970	CY	$15	$14,600	BARR	
Prepare and Roll Subbase	2,900	SY	$1	$2,900	MEANS	
Asphalt Wear Course	2,900	SY	$8	$23,200	MEANS	
Misc. Grading, Establish Drainage,						
Re-spread Topsoil	1	LS	$10,000	$10,000	BARR	
Turf Establisment, Temporary Erosion Control	8	AC	$5,000	$40,000	BARR	
SUBTOTAL SITE RESTORATION:				$91,000		
ESTIMATED TOTAL FIELD COST				$13,471,000		
ESTIMATED TOTAL FIELD COST, EXCLUDING DISPOSAL				$11,796,000		
Bonds (3%)				$354,000		Does not include Disposal Costs for PAH Remediation Zone material.
Insurance (2%)				$236,000		Does not include Disposal Costs for PAH Remediation Zone material.
Contingencies (15%)				$2,021,000 [2]		
ESTIMATED TOTAL CONTRACTOR CONSTRUCTION COST:				$16,082,000		

NOTES:
[1] Unit direct cost includes labor, materials, equipment, overhead, and profit.
[2] Calculated as Contingency Multiplier times Estimated Total Field Cost

Table 5-C-33
Waukegan Manufactured Gas & Coke Plant Site
Non-Contractor Capital Costs
Cost Estimate Details

Alternative 2: Containment
Vadose Zone Soil
Option 2A: Treatment
High Volume

ITEM	ESTIMATED QUANTITY	UNIT	UNIT DIRECT COST [1]	ITEM TOTAL DIRECT COST		SOURCE	COMMENTS
Remedial Design Investigation							
Arsenic Stabilization Treatability Study	1	LS	$30,000	$30,000		BARR	
Soil TCLP Analyses	1	LS	$5,000	$5,000		BARR	
Regulatory Oversight	7	MO	$22,500	$157,500		BARR	
Design	1	LS	$325,000	$325,000		BARR	Includes Work Plan, Design, Construction QAPP, Remedial Action Plan, PHASP, and meetings
Permits/Permitting Assistance	1	LS	$100,000	$100,000			
Engineering Services During Remedial Action	7	MO	$15,000	$105,000		BARR	Includes meetings, design scope changes, etc
Construction Documentation							
Field engineering/construction observation	7	MO	$25,000	$175,000		BARR	Includes monitoring daily field activities during construction
Construction documentation report	1	LS	$55,000	$55,000		BARR	Final report - Includes data, statistical clean-up verification analysis, post-remedy soil management plan
Material testing	1	LS	$236,000	$236,000		BARR	2% of construction costs
SUBTOTAL NON-CONTRACTOR COSTS					$1,189,000		
CONTINGENCY (15%)					$178,000	[2]	

ESTIMATED TOTAL NON-CONTRACTOR CAPITAL COST:	$1,370,000

NOTES:
[1] Unit price includes labor, materials, and equipment
[2] Calculated as Contingency Multiplier times Subtotal Non-Contractor Direct Costs

Table 5-C-34
Waukegan Manufactured Gas & Coke Plant Site
Operation, Maintenance, and Repair Costs
Cost Estimate Details

Alternative 2: Containment
Vadose Zone Soil
Option 2A: Treatment
High Volume

ITEM	ESTIMATED QUANTITY	UNIT	UNIT DIRECT COST [1]	ANNUAL ITEM TOTAL DIRECT COST	FUTURE ITEM TOTAL DIRECT COST	YEAR FUTURE COST OCCURS	PRESENT WORTH OF DIRECT COST[2]	EQUIVALENT ANNUAL COST[2]	SOURCE	COMMENTS
Administration, Inspection, Annual Report	1	LS	$15,000	$15,000			$231,000	$15,000	BARR	
Analysis Review (every 5 years)	1	LS	$11,000			2002	$31,000	$2,000	BARR	
Regulatory Oversight	1	LS	$11,000	$11,000			$169,000	$11,000	BARR	
Maintain Final Cover	1	LS	$2,500	$2,500			$38,000	$3,000	BARR	
SUBTOTAL OM&R COSTS							$469,000	$31,000		
CONTINGENCY (15%)							$70,000	$5,000 [3]		
ESTIMATED TOTAL OPERATION, MAINTENANCE, AND REPAIR COST:							$539,000	$36,000		

NOTES
[1] Unit price includes labor, materials, and equipment
[2] Present Worth values based on a net discount rate of 5% over 30 years
[3] Calculated as Contingency Multiplier times Subtotal Non-Contractor Direct Costs

Table 5-C-35
Waukegan Manufactured Gas & Coke Plant Site
Remediation Contractor Capital Costs
Cost Estimate Details

Alternative 2: Containment
Vadose Zone Soil
Option 2B: Disposal
High Volume

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ITEM	ESTIMATED QUANTITY	UNIT	UNIT DIRECT COST [1]	ITEM TOTAL DIRECT COST		SOURCE	COMMENTS
GENERAL REQUIREMENTS							
Submittals	1	LS	$20,000	$20,000		BARR	Includes contractor preparation of submittals which include work plans, QA plans, drawings, etc
Office	7	MO	$900	$6,300		MEANS	Rental of 2 - 50' x 12' trailer w/ AC
Mobilization	1	LS	$934,810	$934,810		BARR	10% of construction costs, does not include disposal
Demobilization and Decontamination	1	LS	$467,405	$467,405		BARR	5% of construction costs, does not inclued disposal
Utilities	7	MO	$600	$4,200		BARR	Estimate for FAX, telephone, toilets, heat, electricity, water, trash
Potable Water	7	MO	$800	$5,600		BARR	Includes delivered bottled water at 150 ga/week and rental of two coolers
SUBTOTAL GENERAL REQUIREMENTS:					$1,438,000		
SITE WORK							
Connect Utilities	1	LS	$5,000	$5,000		BARR	Includes connection of telephone and electricity to offices
Runon/runoff Control	1	LS	$10,000	$10,000		BARR	Install berms, silt fence, drainage ditches
Clear, Grub, and Subgrade Preparation	13.2	AC	$4,500.00	$59,421		MEANS	Clear & Grub brush, including stumps
Dust Control	7	MO	$4,000	$28,000		BARR	Labor and equipment for 2 hrs/day
Ambient Air Monitoring	7	MO	$15,000	$105,000		BARR	Estimate for monitoring from 3 sampling stations for metals, VOCs, particulates
Vehicle Decontamination Pad	1	LS	$4,000	$4,000		BARR	Construct a lined treatment decon area.
Vehicle Decontamination	7	MO	$5,000	$35,000		BARR	Cost for steam cleaning and operator for decon of all vehicles and equipment leaving the site
Personal Decontamination	7	MO	$1,900	$13,300		HAZCON	18'x24' trailer with negative air and 4 showers. Includes transportation
Water Storage Tanks	7	MO	$5,000	$35,000		BARR	Assume 2 Baker tanks
Access Improvements, Relocate Fence	1	LS	$10,000	$10,000		BARR	Site Improvements
SUBTOTAL SITE WORK:					$305,000		
EXCAVATION, DISPOSAL, AND BACKFILL							
PAH REMEDIATION ZONE							
Strip and Stockpile Overburder	10,700	CY	$3	$32,100		BARR	Assume 6" Overburden Across Site
Remove Existing Asphalt	7,200	SY	$5	$36,000		MEANS	OMC Driveway (South of Site)
Asphalt Disposal	1,800	CY	$30	$54,000		BARR	Recycle, includes transportation and disposal
Excavate Soil, Separate PAH Material	29,300	CY	$20	$586,000		BARR	14,900 CY of tar & oily soil, 14,400 cy of overburden
Soil Mixing and Loading	33,500	Ton	$40	$1,340,000		BARR	Mix tar with oily soil to allow for handling, loading, and unloading
Sampling and Testing	33,500	Ton	$10	$335,000		BARR	
Load and Haul PAH Material	33,500	Ton	$33	$1,105,500		PDC	
Disposal at RCRA Subtitle C Landfill	33,500	Ton	$75	$2,512,500		PDC	Disposal in Peoria, IL
Dewatering, Pre-Treatment, and Disposal of Water During Excavation	2,800	1,000 Gal	$400	$1,120,000		BARR	Treatment through treatment system ($0.30/gal), discharge to POTW ($0.10/gal)
ARSENIC REMEDIATON ZONE							
Set Up Segregation Area and Equipment	1	LS	$100,000	$100,000		BARR	Concrete pad for soil processing equipment, asphalt pad, concrete walls for staging
Excavate Soil and Segregate Debris	7,200	CY	$20	$144,000		BARR	
Sampling and Testing	10,800	Ton	$10	$108,000		BARR	
Load and Haul Arsenic Material	10,800	Ton	$33	$356,400		PDC	
Disposal at RCRA Subtitle C Landfill	10,800	Ton	$100	$1,080,000		PDC	Includes stabilization of Arsenic and disposal in Peoria, IL
Clean Debris	1,080	Ton	$20	$21,600		BARR	Debris consists of bricks, rebar, concerete,timber, and pipe; assume 10% debris by weigh
Load and Haul Debris to Local Landfill	1,080	Ton	$10	$10,800		BARR	
Debris Disposal at Landfill	1,080	Ton	$20	$21,600		BARR	
BACKFILL							
Load, Haul, Backfill, and Compact Soil from Designated Stockpile and Overburden	19,400	CY	$5	$97,000		BARR	
Backfill from Off-Site Source	17,100	CY	$12	$205,200		BARR	Includes $10/cy for material and delivery to site and $2/cy for installation
SUBTOTAL EXCAVATION, TREATMENT, DISPOSAL, AND BACKFILL:					$9,266,000		

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Table 5-C-35 (continued)
Waukegan Manufactured Gas & Coke Plant Site
Remediation Contractor Capital Costs
Cost Estimate Details

Alternative 2: Containment
Vadose Zone Soil
Option 2B: Disposal
High Volume

ITEM	ESTIMATED QUANTITY	UNIT	UNIT DIRECT COST [1]	ITEM TOTAL DIRECT COST	SOURCE	COMMENTS
ASPHALT CAPPING						
CAP CONSTRUCTION						
Import Fill for Grading/Shaping	21,300	SF	$12	$255,600	BARR	One foot cover over cap area
60-mil HDPE Geomembrane	575,200	SF	$0.85	$488,900	BARR	Reduce Permeability
Protective Cover	21,300	CY	$15	$319,500	BARR	12" Granular Drainage Material Over HDPE
Aggregate Subbase	21,300	CY	$15	$319,500	BARR	12" Thick
Prepare and Roll Subbase	63,900	SY	$1	$63,900	MEANS	
Asphalt Wear Course	63,900	SY	$8	$511,200	MEANS	3" Thick
Asphalt Berm Curb	3,900	LF	$2	$7,800	MEANS	
MISCELLANEOUS						
Re-align Storm Sewer	500	LF	$70	$35,000	BARR	Includes restoration of lawn, parking lot, and manholes
De-watering/Pre-treatment, Disposal of Water During						
Storm Sewer Work	1	LS	$20,000	$20,000	BARR	Treatment through treatment system ($0.30/gal), discharge to POTW ($0.10/gal)
Abandon Monitoring Wells	4	EA	$3,000	$12,000	BARR	MW-9S,D; MW-7S,D
SUBTOTAL ASPHALT CAPPING:				$2,033,000		
STORMWATER DETENTION POND AND APPURTENANCES						
Catch Basins	6	EA	$2,000	$12,000	BARR	1 Catch Basin/2 acres of cap
Piping Between Catch Basins	2,000	LF	$50	$100,000	BARR	
Manholes	2	EA	$2,500	$5,000	BARR	
Excavation	24,000	CY	$10	$240,000	BARR	
HDPE Liner	152,500	SF	$0.85	$129,625	BARR	
Backfill	2,800	CY	$5	$14,000	BARR	On-site material
Outlet Structure	1	EA	$10,000	$10,000	BARR	
Outlet Pipe	150	LF	$75	$11,250	BARR	Outlet to harbor
SUBTOTAL STORMWATER DETENTION POND AND APPURTENANCES:				$522,000		
SITE RESTORATION						
Restore Asphalt						OMC Driveway (South of Site)
Aggregate Subbase	970	CY	$15	$14,600	BARR	
Prepare and Roll Subbase	2,900	SY	$1	$2,900	MEANS	
Asphalt Wear Course	2,900	SY	$8	$23,200	MEANS	
Misc. Grading, Establish Drainage,						
Re-spread Topsoil	1	LS	$10,000	$10,000	BARR	
Turf Establisment, Temporary Erosion Control	8	AC	$5,000	$40,000	BARR	
SUBTOTAL SITE RESTORATION:				$91,000		
ESTIMATED TOTAL FIELD COST				$13,655,000		
ESTIMATED TOTAL FIELD COST, EXCLUDING DISPOSAL				$10,062,500		
Bonds (3%)				$302,000		Does not include Disposal Costs for PAH Remediation Zone material.
Insurance (2%)				$201,000		Does not include Disposal Costs for PAH Remediation Zone material.
Contingencies (15%)				$2,048,000 [2]		
ESTIMATED TOTAL CONTRACTOR CONSTRUCTION COST:				$16,206,000		

NOTES:
[1] Unit direct cost includes labor, materials, equipment, overhead, and profit.
[2] Calculated as Contingency Multiplier times Estimated Total Field Cos

Table 5-C-36
Waukegan Manufactured Gas & Coke Plant Site
Non-Contractor Capital Costs
Cost Estimate Details

Alternative 2: Containment
Vadose Zone Soil
Option 2B: Disposal
High Volume

ITEM	ESTIMATED QUANTITY	UNIT	UNIT DIRECT COST [1]	ITEM TOTAL DIRECT COST		SOURCE	COMMENTS
Remedial Design Investigation							
Soil TCLP Analyses	1	LS	$5,000	$5,000		BARR	
Regulatory Oversight	7	MO	$22,500	$157,500		BARR	
Design	1	LS	$325,000	$325,000		BARR	Includes Work Plan, Design, Construction QAPP, Remedial Action Plan, PHASP, and meetings
Permits/Permitting Assistance	1	LS	$100,000	$100,000		BARR	
Engineering Services During Remedial Action	7	MO	$15,000	$105,000		BARR	Includes meetings, design scope changes, etc
Construction Documentation							
Field engineering/construction observation	7	MO	$25,000	$175,000		BARR	Includes monitoring daily field activities during construction
Construction documentation report	1	LS	$55,000	$55,000		BARR	Final report - Includes data, statistical clean-up verification analysis, post-remedy soil management plan
Material testing	1	LS	$201,000	$201,000		BARR	2% of construction costs
SUBTOTAL NON-CONTRACTOR COSTS					$1,124,000		
CONTINGENCY (15%)					$169,000 [2]		

ESTIMATED TOTAL NON-CONTRACTOR CAPITAL COST:	$1,290,000

NOTES:
[1] Unit price includes labor, materials, and equipment
[2] Calculated as Contingency Multiplier times Subtotal Non-Contractor Direct Costs

Table 5-C-37
Waukegan Manufactured Gas & Coke Plant Site
Operation, Maintenance, and Repair Costs
Cost Estimate Details

Alternative 2: Containment
Vadose Zone Soil
Option 2B: Disposal
High Volume

ITEM	ESTIMATED QUANTITY	UNIT	UNIT DIRECT COST [1]	ANNUAL ITEM TOTAL DIRECT COST	FUTURE ITEM TOTAL DIRECT COST	YEAR FUTURE COST OCCURS	PRESENT WORTH OF DIRECT COST [2]	EQUIVALENT ANNUAL COST [2]	SOURCE	COMMENTS
Administration, Inspection, Annual Report	1	LS	$15,000	$15,000			$231,000	$15,000	BARR	
Analysis Review (every 5 years)	1	LS	$11,000			2002	$31,000	$2,000	BARR	
Regulatory Oversight	1	LS	$11,000	$11,000			$169,000	$11,000	BARR	
Maintain Final Cover	1	LS	$2,500	$2,500			$38,000	$3,000	BARR	
SUBTOTAL OM&R COSTS							$469,000	$31,000		
CONTINGENCY (15%)							$70,000	$5,000 [3]		
ESTIMATED TOTAL OPERATION, MAINTENANCE, AND REPAIR COST							$539,000	$36,000		

NOTES:
[1] Unit price includes labor, materials, and equipment.
[2] Present Worth values based on a net discout rate of 5% over 30 years
[3] Calculated as Contingency Multiplier times Subtotal Non-Contractor Direct Costs

Table 5-C-38
Waukegan Manufactured Gas & Coke Plant Site
Remediation Contractor Capital Costs
Cost Estimate Details

Alternative 2: Containment
Vadose Zone Soil
Option 2C: Containment
High Volume

ITEM	ESTIMATED QUANTITY	UNIT	UNIT DIRECT COST [1]	ITEM TOTAL DIRECT COST	SOURCE	COMMENTS
GENERAL REQUIREMENTS						
Submittals	1	LS	$20,000	$20,000	BARR	Includes contractor preparation of submittals which include work plans, QA plans, drawings, etc.
Office	8	MO	$900	$7,200	MEANS	Rental of 2 - 50' x 12' trailers w/ AC
Mobilization	1	LS	$682,000	$682,000	BARR	10% of construction costs
Decontamination and Demobiliztion	1	LS	$341,000	$341,000	BARR	5% of construction costs
Utilities	8	MO	$600	$4,800	BARR	Estimate for FAX, telephone, toilets, heat, electricity, water, trash
Potable Water	8	MO	$800	$6,400	BARR	Includes delivered bottled water at 150 gal/week and rental of two coolers.
SUBTOTAL GENERAL REQUIREMENTS:				$1,061,000		
SITE WORK						
Connect Utilities	1	LS	$5,000	$5,000	BARR	Includes connection of telephone and electricity to offices.
Runon/runoff Control	1	LS	$10,000	$10,000	BARR	Install berms, silt fence, drainage ditches.
Clear and Grub	13.2	AC	$4,500	$59,400	MEANS	Clear and grub brush, including stumps
Dust Control	8	MO	$4,000	$32,000	BARR	Labor and equipment for 2 hrs/day
Ambient Air Monitoring	8	MO	$15,000	$120,000	BARR	Estimate for monitoring from 3 sampling stations for metals, SVOCs, VOCs, particulates.
Vehicle Decontamination Pad	8	LS	$4,000	$32,000	BARR	Construct a lined treatment decon area.
Vehicle Decontamination	8	MO	$5,000	$40,000	BARR	Cost for steam cleaning and operator for decon of all vehicles and equipment leaving the site.
Personal Decontamination	8	MO	$1,900	$15,200	HAZCON	18'x24' trailer with negative air and 4 showers. Includes transportation.
Water Storage Tanks	8	MO	$5,000	$40,000	BARR	Assume 2 Baker tanks
Access Improvement, Relocate Fence	1	LS	$15,000	$15,000	BARR	Site improvements
SUBTOTAL SITE WORK:				$369,000		
VAULT SUBGRADE PREPARATION						
Strip and Stockpile Overburden	10,700	CY	$3	$32,100	BARR	Assume 6" overburden across site
Subgrade Excavation and Stockpiling, and Debris Management and Soil Segregation	40,700	CY	$10	$407,000	BARR	5' Excavation beneath proposed vault location
De-watering, Pre-treatment, Disposal of Water During Excavation	410	1,000 Gal	$400	$164,000	BARR	Treatment through treatment system ($0.30/gal), discharge to POTW ($0.10/gal)
Backfill and Compact Subgrade						Backfill to 3' below existing ground
On-Site Material (Designated Soil Stockpile)	5,000	CY	$5	$25,000	BARR	
Off-Site Material	11,300	CY	$12	$135,600	BARR	Includes $10/cy for material and delivery to site and $2/cy for installation
SUBTOTAL VAULT SUBGRADE PREPARATION:				$764,000		
VAULT & COVER CONSTRUCTION AND APPURTENANCES						
BERM	18,700	CY	$5	$93,500	BARR	Assume on-site material from subgrade excavation
LINER						
Secondary Liner - Composite Liner						
Compacted clay - 3 ft	12,300	CY	$15	$184,500	LAKE COUNTY	Includes $10/cy for delivery to site, $5/cy for processing, placing, and compacting
60-mil HDPE membrane	141,300	SF	$0.85	$120,100	BARR	Add 10% to total surface area quantity to account for anchor trenches
Granular drainage material - 12 in	4,100	CY	$15	$61,500	MIDWEST AGG.	
6-inch HDPE collection pipe with aggregate filter	2,500	LF	$25	$62,500	BARR/MIDWEST AGG.	Leachate collection/Leak detection system, includes coarse aggregate filter
Primary Liner						
60-mil HDPE membrane	141,300	SF	$0.85	$120,100	BARR	Add 10% to total surface area quantity to account for anchor trenches
Granular drainage material - 12 in	4,100	CY	$15	$61,500	MIDWEST AGG.	
6-inch HDPE collection pipe with aggregate filter	2,500	LF	$25	$62,500	BARR/MIDWEST AGG.	Leachate collection, includes coarse aggregate filter
COVER						
Protective Cover - 6 in granular drainage material	2,300	CY	$15	$34,500	MIDWEST AGG.	
Low Permeability Layer						
40-mil LDPE membrane	125,900	SF	$0.75	$94,400	BARR	
Final Protective Layer						
Granular drainage material - 12 in	4,700	CY	$15	$70,500	MIDWEST AGG.	
Perforated drain tile with pea gravel filter	2,000	LF	$5	$10,000	MEANS	Installed at perimeter of cap, includes $2/lf for drain tile, $3/lf for pea gravel
Rooting zone material - 18 in	7,000	CY	$12	$84,000	BARR	Includes $10/cy for material and delivery to site, $2/cy for installation
Topsoil - 6 in	2,300	CY	$16	$36,800	BARR	Includes $14/cy for material and delivery to site, $2/cy for installation
Gas Vents	8	EA	$400	$3,200	BARR	
MISCELLANEOUS						
Leachate Storage Tank	1	EA	$55,000	$55,000	BARR	
Leachate Manhole	1	EA	$11,000	$11,000	BARR	
Leachate Pump and Controls	1	LS	$11,000	$11,000	BARR	
Leachate Pre-treatment System	1	LS	$10,000	$10,000	BARR	
Leachate Treatment During Construction	1	LS	$10,000	$10,000	BARR	
Site Perimeter Fence	1	LS	$35,000	$35,000	BARR	6' chain link fence ($20/LF) w/ barbed wire and 20' wide gate
SUBTOTAL VAULT & COVER CONSTRUCTION AND APPURTENANCES:				$1,232,000		

Table 5-C-38 (continued)
Waukegan Manufactured Gas & Coke Plant Site
Remediation Contractor Capital Costs
Cost Estimate Details

Alternative 2: Containment
Vadose Zone Soil
Option 2C: Containment
High Volume

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ITEM	ESTIMATED QUANTITY	UNIT	UNIT DIRECT COST [1]	ITEM TOTAL DIRECT COST		SOURCE	COMMENTS
WASTE EXCAVATION AND HAULING							
Remove Existing Asphalt	7,200	SY	$5	$36,000		MEANS	OMC Driveway (South of Site)
Asphalt Disposal	1,800	CY	$30	$54,000		BARR	Recycle, Includes transportation and disposal
Excavate Soil, Segregate PAH and Arsenic Soil	36,500	CY	$20	$730,000		BARR	14,300 cy of PAH Remediation Zone Material and 3,300 cy of Arsenic Remediaton Zone Material
Load and Haul Remediaton Zone Material	26,500	CY	$5	$132,500		BARR	Assumes 20% swell during excavation and hauling
Place and Compact Soil in Containment Unit and Management of Debris	22,100	CY	$10	$221,000		BARR	
De-watering, Pre-treatment, Disposal of Water	2,800	1,000 Gal	$400	$1,120,000		BARR	Treatment through treatment system ($0.30/gal), discharge to POTW ($0.10/gal)
Backfill From Off-site Source	22,100	CY	$12	$265,000		BARR	Includes $10/cy for material and delivery to site, $2/cy for installation
SUBTOTAL WASTE EXCAVATION AND HAULING:					$2,559,000		
ASPHALT CAPPING							
CAP CONSTRUCTION							
Import Fill for Grading/Shaping	13,200	CY	$12	$158,400		BARR	One foot cover over cap area
60-mil HDPE Geomembrane	355,400	SF	$0.85	$302,100		BARR	Reduce Permeability
Protective Cover	13,200	CY	$15	$198,000		BARR	12" Granular Drainage Material Over HDPE
Aggregate Subbase	13,200	CY	$15	$198,000		BARR	12" Thick
Prepare and Roll Subbase	39,500	SY	$1	$39,500		MEANS	
Asphalt Wear Course	39,500	SY	$8	$316,000		MEANS	3" Thick
Asphalt Berm Curb	3,000	LF	$2	$6,000		MEANS	
MISCELLANEOUS							
Re-align Storm Sewer	500	LF	$70	$35,000		BARR	Includes restoration of lawn, parking lot, and manholes
De-watering/Pre-treatment, Disposal of Water During Storm Sewer Work	1	LS	$20,000	$20,000		BARR	Treatment through treatment system ($0.30/gal), discharge to POTW ($0.10/gal)
Abandon Monitoring Wells	4	EA	$3,000	$12,000		BARR	MW-9S,D: MW-7S,D
SUBTOTAL ASPHALT CAPPING					$1,285,000		
STORMWATER DETENTION POND AND APPURTENANCES							
Catch Basins	4	EA	$2,000	$8,000		BARR	1 Catch Basin/2 acres of cap
Piping Between Catch Basins	2,000	LF	$50	$100,000		BARR	
Manholes	2	EA	$2,500	$5,000		BARR	
Excavation	24,000	CY	$10	$240,000		BARR	
HDPE Liner	152,500	SF	$0.85	$129,625		BARR	
Backfill	2,800	CY	$5	$14,000		BARR	On-site material
Outlet Structure	1	EA	$10,000	$10,000		BARR	
Outlet Pipe	150	LF	$75	$11,250		BARR	Outlet to harbor
SUBTOTAL STORMWATER DETENTION POND AND APPURTENANCES:					$518,000		
SITE RESTORATION							
Restore Asphalt							OMC Driveway (South of Site)
Aggregate Subbase	970	CY	$15	$14,550		BARR	
Prepare and Roll Subbase	2,900	SY	$1	$2,900		MEANS	
Asphalt Wear Course	2,900	SY	$8	$23,200		MEANS	
Misc. Grading, Establish Drainage, Re-spread Topsoil	1	LS	$10,000	$10,000		BARR	
Turf Establisment, Temporary Erosion Control	8	AC	$5,000	$40,000		BARR	
SUBTOTAL SITE RESTORATION:					$91,000		
ESTIMATED TOTAL FIELD COST				$7,879,000			
Bonds (3%)				$236,000			
Insurance (2%)				$158,000			
Contingencies (15%)				$1,182,000 [2]			
ESTIMATED TOTAL CONTRACTOR CONSTRUCTION COST:					$9,455,000		

NOTES:
[1] Unit direct cost includes labor, materials, equipment, overhead, and profit.
[2] Calculated as Contingency Multiplier times Estimated Total Field Cost

Table 5-C-39
Waukegan Manufactured Gas & Coke Plant Site
Non-Contractor Capital Costs
Cost Estimate Details

Alternative 2: Containment
Vadose Zone Soil
Option 2C: Containment
High Volume

ITEM	ESTIMATED QUANTITY	UNIT	UNIT DIRECT COST [1]	ITEM TOTAL DIRECT COST		SOURCE	COMMENTS
Remedial Design Investigation							
Soil TCLP Analyses	1	LS	$5,000	$5,000		BARR	
Regulatory Oversight	8	MO	$50,000	$400,000		BARR	
Design	1	LS	$425,000	$425,000		BARR	Includes Work Plan, Design, Construction QAPP, Remedial Action Plan, PHASP, and meetings
Permits/Permitting Assistance	1	LS	$150,000	$150,000		BARR	
Engineering Services for Remedial Action	8	MO	$15,000	$120,000		BARR	Includes meetings, design scope changes, etc.
Construction Documentation							
Field engineering/construction observation	8	MO	$25,000	$200,000		BARR	Includes monitoring daily field activities during construction
Construction documentation report	1	LS	$55,000	$55,000		BARR	Final report - Includes data, statistical clean-up verification analysis, post-remedy soil management plan
Material testing	1	LS	$158,000	$158,000		BARR	2% of construction costs
SUBTOTAL NON-CONTRACTOR COSTS					$1,513,000		
CONTINGENCY (15%)					$227,000 [2]		
ESTIMATED TOTAL NON-CONTRACTOR CAPITAL COST:					$1,740,000		

NOTES:
[1] Unit price includes labor, materials, and equipment.
[2] Calculated as Contingency Multiplier times Subtotal Non-Contractor Direct Costs

Table 5-C-40
Waukegan Manufactured Gas & Coke Plant Site
Operation, Maintenance, and Repair Costs
Cost Estimate Details

Alternative 2: Containment
Vadose Zone Soil
Option 2C: Containment
High Volume

ITEM	ESTIMATED QUANTITY	UNIT	UNIT DIRECT COST [1]	ANNUAL ITEM TOTAL DIRECT COST	FUTURE ITEM TOTAL DIRECT COST	YEAR FUTURE COST OCCURS	PRESENT WORTH OF DIRECT COST [2]	EQUIVALENT ANNUAL COST [2]	SOURCE	COMMENTS
Administration, Inspection, Annual Report	1	LS	$15,000	$15,000			$231,000	$15,000	BARR	
Analysis Review (every 5 years)	1	LS	$50,000			2003, 2008,...	$139,000	$9,000	BARR	
Regulatory Oversight	1	LS	$11,000	$11,000			$169,000	$11,000	BARR	
Maintain Final Cover	1	LS	$2,500	$2,500			$38,000	$3,000	BARR	
Leachate Collection, Treatment, Disposal	1	LS	$10,000	$10,000			$154,000	$10,000	BARR	
SUBTOTAL OM&R COSTS							$731,000	$48,000		
CONTINGENCY (15%)							$110,000	$7,000 [3]		
ESTIMATED TOTAL OPERATION, MAINTENANCE, AND REPAIR COST:							$840,000	$55,000		

NOTES:
[1] Unit price includes labor, materials, and equipment
[2] Present Worth values based on a net discount rate of 5% over 30 years
[3] Calculated as Contingency Multiplier times Subtotal Non-Contractor Direct Costs

Table 5-C-41
Waukegan Manufactured Gas & Coke Plant Site   **Alternative 2: Containment**
Remediation Contractor Capital Costs   **Groundwater**
Cost Estimate Details [1]   **High Cost**

ITEM	ESTIMATED QUANTITY	UNIT	UNIT DIRECT COST [2]	ITEM TOTAL DIRECT COST		SOURCE	COMMENTS
GENERAL REQUIREMENTS							
Submittals	1	LS	$20,000	$20,000		BARR	Includes contractor preparation of submittals which include work plans, QA plans, drawings, etc.
Office	7	MO	$900	$6,300		MEANS	Rental of 2 - 50' x 12' trailer w/ AC. 3 months for slurry wall construction, 4 months for cell install and s¹
Mobilization	1	LS	$710,000	$710,000		BARR	10% of construction costs
Demobilization and Decontamination	1	LS	$350,000	$350,000		BARR	5% of construction costs
Utilities	7	MO	$600	$4,200		BARR	Estimate for FAX, telephone, toilets, heat, electricity, water, trash
Potable Water	7	MO	$800	$5,600		BARR	Includes delivered bottled water at 150 ga/week and rental of two coolers.
SUBTOTAL GENERAL REQUIREMENTS					$1,100,000		
SITE WORK							
Dust Control	4	MO	$4,000	$16,000		BARR	Labor and equipment for 2 hrs/day, during slurry wall activities.
Ambient Air Monitoring	4	MO	$15,000	$60,000		BARR	Estimate for monitoring from 3 sampling stations for metals, VOCs, particulates.
Vehicle Decontamination	2	MO	$5,000	$10,000		BARR	Cost for steam cleaning and operator for decon of all vehicles and equipment leaving the site.
Personal Decontamination	2	MO	$1,900	$3,800		HAZCON	18'x24' trailer with negative air and 4 showers. Includes transportation.
SUBTOTAL SITE WORK					$90,000		
Slurry Wall	100,000	SF	$20	$2,000,000		BARR	4,000 ft slurry wall, 30 ft deep
Groundwater Extraction Wells	2	WELL	$25,000	$50,000		BARR	Includes pumps, piping, and controls.
SUBTOTAL SLURRY WALL					$2,100,000		
GROUNDWATER EXTRACTION / INFILTRATION SYSTEM							
Groundwater pump	4	EA	$12,000	$48,000		NEEP SYSTEMS	EconoPump Multi-well jet system, one unit per cell.
Groundwater pump controls	4	EA	$20,000	$80,000			Power supply, controls, and plumbing
Piping - 24" diameter corrugated PEP	1800	LF	$35	$63,000		BARR	Conduit to house piping
Install manholes	10	EA	$2,500	$25,000		BARR	Manholes along conduit
Piping - 1" diameter	54000	LF	$2	$110,000		BARR	1" diameter polyethylene piping between wells and pump, and to reinjection cells.
36" RCP Under Road	260	LF	$75	$20,000		BARR	Casing pipe for well lines. Includes open cut and asphalt restoration
Install monitoring wells	30	WELL	$5,000	$150,000		BARR	Additional groundwater monitoring well nests.
SUBTOTAL GROUNDWATER EXTRACTION					$500,000		

NOTES:
[1] Includes costs through completion of treatment and disposal
[2] Unit direct cost includes labor, materials, equipment, overhead, and profit
[3] Calculated as Contingency Multiplier times Contractor Subtotal Direct Costs

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Table 5-C-41 (continued)
Waukegan Manufactured Gas & Coke Plant Site   Alternative 2: Containment
Remediation Contractor Capital Costs   Groundwater
Cost Estimate Details [1]   High Cost

ITEM	ESTIMATED QUANTITY	UNIT	UNIT DIRECT COST [2]	ITEM TOTAL DIRECT COST		SOURCE	COMMENTS
WATER TREATMENT - 60 GPM							
Utilities	1	LS	$30,000	$30,000		BARR	$15K power, $10K sewer, $5K water, telephone, etc.
Building for Treatment Equipment	4100	SF	$100	$410,000		BARR	
HVAC for Treatment Building	4100	SF	$10	$41,000		MEANS	
Electrical for Treatment Building	4100	SF	$9	$37,000		MEANS	
Concrete Slab / Footings	550	CY	$500	$280,000		BARR	Assumes 12" thick slab
System Assembly	1500	HR	$50	$75,000		BARR	
Pipes, Pumps & Equipment	1	LS	$150,000	$150,000		BARR	
Total System Startup	400	HR	$100	$40,000		BARR	
Startup Sampling	200	SMPL	$1,000	$200,000		BARR	
Field Pilot Study							
Equipment - Andco	6	MO	$20,000	$120,000		ANDCO	Andco equipment rental.
Equipment - Zimpro PACT	6	MO	$25,000	$150,000		ZIMPRO	Zimpro equipment rental.
Transportation of Equipment	1	LS	$5,000	$5,000		BARR	
Operation	6	MO	$5,800	$35,000		BARR	Operator 24 hours per week at $60 per hour.
Sampling	430	SMPL	$1,000	$430,000		BARR	14 sampling events, 30 samples per event, plus 6 samples over first 2 weeks.
Installation & Startup	200	HR	$100	$20,000		BARR	
Electrochemical Precipitation							
Equipment	1	LS	$160,000	$160,000		ANDCO	Arsenic removal.
Transportation of equipment	1	LS	$5,000	$5,000		ANDCO	
Installation & Startup	1	LS	$20,000	$20,000		BARR	Andco support for start-up.
Activated Sludge with PAC							
PACT System Equipment	1	LS	$600,000	$600,000		ZIMPRO	Phenol and organics removal.
Transportation & Installation	1	LS	$195,000	$195,000		ZIMPRO	
Activated Sludge with PAC - Ammonia							
PACT System Equipment	1	LS	$1,100,000	$1,100,000		ZIMPRO	Ammonia nitrification and denitrification (90%).
Transportation & Installation	1	LS	$300,000	$300,000		ZIMPRO	
SUBTOTAL WATER TREATMENT					$4,400,000		

SUBTOTAL CONTRACTOR DIRECT COST	$8,200,000
BONDS (3%)	$250,000
INSURANCE (2%)	$160,000
CONTINGENCY [3] (15%)	$1,200,000
ESTIMATED TOTAL CONTRACTOR CONSTRUCTION COST	$9,800,000

NOTES:
[1] Includes costs through completion of treatment and disposal
[2] Unit direct cost includes labor, materials, equipment, overhead, and profit
[3] Calculated as Contingency Multiplier times Contractor Subtotal Direct Costs

Table 5-C-42

Waukegan Manufactured Gas & Coke Plant Site	**Alternative 2: Containment**					12:45 PM
Non-Contractor Capital Costs	**Groundwater**					
Cost Estimate Details [1]	**High Cost**					

ITEM	ESTIMATED QUANTITY	UNIT	UNIT DIRECT COST [2]	ITEM TOTAL DIRECT COST	SOURCE	COMMENTS
Remedial Design Investigation						
Groundwater monitoring wells	1	LS	$200,000	$200,000	BARR	Includes installation of 20 additional monitoring well nests, and geoprobe costs at $1200/day for 2 days
Groundwater sampling	1	LS	$50,000	$50,000	BARR	Sampling and analysis of 22 monitoring well nests and 6 geoprobes
Surface water sampling	1	LS	$100,000	$100,000	BARR	Includes 2 surface water sampling events at $50,000 each
Pilot Study						
Work Plan & Coordination	1	LS	$30,000	$30,000	BARR	Design.
Engineering Oversight	6	MO	$10,000	$60,000	BARR	Engineering oversight during pilot study.
Final Report	1	LS	$30,000	$30,000	BARR	Regulatory oversight during construction activities.
Design	1	LS	$350,000	$350,000	BARR	Includes work plan, treatment system, cell, and slurry wall design, QA/QC plan, SHSP, and meetings
Bidding/Bidding Administration	1	LS	$30,000	$30,000	BARR	
Permits/Permitting Assistance	1	LS	$50,000	$50,000	BARR	
Regulatory Oversight	7	MO	$22,500	$158,000	BARR	Regulatory oversight during construction activities.
Engineering Services for Remedial Action	6	MO	$15,000	$90,000	BARR	Includes construction meetings, changes to plans and specifications, etc.
Field engineering/construction observation	6	MO	$25,000	$150,000	BARR	Includes monitoring daily field activities for 6 months.
H & S Monitoring/Air Monitoring	3	MO	$7,000	$21,000	BARR	Includes health and safety specialist.
Slurry Wall Testing	1	LS	$40,000	$40,000	BARR	2% of slurry wall construction costs.
Construction documentation report	1	LS	$65,000	$65,000	BARR	Final report, including slurry wall testing documentation.
SUBTOTAL NON-CONTRACTOR COSTS				$1,400,000		
CONTINGENCY (15%) [3]				$210,000		
ESTIMATED TOTAL NON-CONTRACTOR CAPITAL COST				$1,600,000		

NOTES:
[1] Includes costs through completion of treatment and disposal
[2] Unit direct cost includes labor, materials, equipment, overhead, and profit
[3] Calculated as Contingency Multiplier times Contractor Subtotal Direct Costs

Table 5-C-43
Waukegan Manufactured Gas & Coke Plant Site
Operation, Maintenance, and Repair Costs
Cost Estimate Details [1]

Alternative 2: Containment
Groundwater
High Cost

ITEM	ESTIMATED QUANTITY	UNIT	UNIT DIRECT COST [2]	ANNUAL ITEM TOTAL DIRECT COST	FUTURE ITEM TOTAL DIRECT COST	YEAR FUTURE COST OCCURS	PRESENT WORTH OF DIRECT COST [4]	EQUIVALENT ANNUAL COST [4]	SOURCE	COMMENTS
TREATMENT CELLS										Four treatment cells installed and operated per year.
Sampling, Analysis, Reporting	1	LS	$200,000	$200,000			$1,500,000	$200,000	BARR	
Wellpoint Installation	120	WELL	$600	$72,000			$560,000	$72,000	MEANS	For one treatment cell: 10 pumping, 20 reinjection wells.
Additional Piping - 1" diameter	24000	LF	$2	$48,000			$370,000	$48,000	BARR	1" diameter polyethylene required for moving the treatment cells.
Repair, Maintenance	1	LS	$80,000	$80,000			$620,000	$80,000	BARR	Well and pump maintenance.
SUBTOTAL CELL OM&R COSTS							$3,100,000	$400,000		
years 1 - 10										
Engineering Oversight	500	HR	$100	$50,000			$390,000	$50,000	BARR	
WATER TREATMENT										
Heating and Cooling of Treatment Building	1	LS	$40,000	$40,000			$310,000	$40,000		Includes winter heating of outdoor tanks.
ELECTROCHEMICAL PRECIPITATION										
Annual Report	1	LS	$10,000	$10,000			$77,000	$10,000		Arsenic removal.
Sampling, Analysis, Reporting	30	SAMPLE	$500	$15,000			$120,000	$15,000		
Residual Transport and Disposal	20	TON	$100	$2,000			$15,000	$2,000	BARR	Disposal of Sludge in a Subtitle D Landfill
Labor for Operation	3000	HR	$50	$150,000			$1,200,000	$150,000		Operator assumed 8 hours per day, 7 days per week.
Power and Iron Costs	32000	1000 GAL	$0.33	$11,000			$85,000	$11,000		Cost per 1000 gallons treated.
PACT SYSTEM - PHENOL/ORGANICS REMOVAL										Phenol and organics removal.
Annual Report	1	LS	$10,000	$10,000			$77,000	$10,000		
Sampling, Analysis, Reporting	30	SAMPLE	$500	$15,000			$120,000	$15,000		
Residual Transport and Disposal	80	TON	$100	$8,000			$62,000	$8,000	BARR	Disposal of Sludge in a Subtitle D Landfill
Labor for Operation Optimization	3000	HR	$50	$150,000			$1,200,000	$150,000		Operator assumed 8 hours per day, 7 days per week.
Power and Chemical Costs	365	DAY	$95	$35,000			$270,000	$35,000		
PACT SYSTEM - AMMONIA REMOVAL										Ammonia nitrification and denitrification (90%).
Annual Report	1	LS	$10,000	$10,000			$77,000	$10,000		
Sampling, Analysis, Reporting	30	SAMPLE	$500	$15,000			$120,000	$15,000		
Residual Transport and Disposal	80	TON	$100	$8,000			$62,000	$8,000	BARR	Disposal of Sludge in a Subtitle D Landfill
Labor for Operation Optimization	3000	HR	$50	$150,000			$1,200,000	$150,000		Operator assumed 8 hours per day, 7 days per week.
Power and Chemical Costs	365	DAY	$165	$60,000			$460,000	$60,000		
Carbon Source Addition for Denitrification	365	DAY	$100	$37,000			$290,000	$37,000		
Groundwater Monitoring	160	SAMPLE	$1,000	$160,000			$1,200,000	$160,000		
SUBTOTAL WATER TREATMENT OM&R COSTS (years 1-10)							$7,300,000	$940,000		
TREATMENT EQUIPMENT (years 1-10)										
Replace Wells (every 10 years)	2	WELL	$25,000	$50,000		2008	$31,000	$4,000		
Pipes, Pumps, and Equipment	1	LS	$15,000	$15,000			$120,000	$15,000	BARR	10% of equipment capital cost
Electrochemical Precipitation Equipment	1	LS	$32,000	$32,000			$250,000	$32,000	BARR	20% of equipment capital cost
PACT System Equipment	1	LS	$24,000	$24,000			$190,000	$24,000	BARR	4% of equipment capital cost
PACT System Equipment - Ammonia Removal	1	LS	$44,000	$44,000			$340,000	$44,000	BARR	4% of equipment capital cost
SUBTOTAL TREATMENT EQUIPMENT M&R COSTS (years 1-10)							$930,000	$120,000		

NOTES:
[1] Includes costs through completion of treatment and disposal.
[2] Unit direct cost includes labor, materials, equipment, overhead, and profit.
[3] Calculated as Contingency Multiplier times Subtotal Direct Costs
[4] Present Worth values based on a net discount rate of 5% over 10 years

Table 5-C-43 (continued)
Waukegan Manufactured Gas & Coke Plant Site
Operation, Maintenance, and Repair Costs
Cost Estimate Details [1]

Alternative 2: Containment
Groundwater
High Cost

ITEM	ESTIMATED QUANTITY	UNIT	UNIT DIRECT COST [2]	ANNUAL ITEM TOTAL DIRECT COST	FUTURE ITEM TOTAL DIRECT COST	YEAR FUTURE COST OCCURS	PRESENT WORTH OF DIRECT COST [4]	EQUIVALENT ANNUAL COST [4]	SOURCE	COMMENTS
years 11 - 30										
Engineering Oversight	100	HR	$100	$10,000			$80,000	$6,400	BARR	
										Cells are no longer operating.
WATER TREATMENT										Treatment of water withdrawn from within slurry wall only, approx 1G
Heating and Cooling of Treatment Building	1	LS	$40,000	$40,000			$310,000	$24,900		
ELECTROCHEMICAL PRECIPITATION										
Annual Report	1	LS	$10,000	$10,000			$80,000	$6,400		Arsenic removal.
Sampling, Analysis, Reporting	30	SAMPLE	$500	$15,000			$110,000	$8,800		
Residual Transport and Disposal	0.3	TON	$100	$30			$230	$20	BARR	Disposal of Sludge in a Subtitle D Landfill (1/60 of quantity for 0-5 yea
Labor for Operation	750	HR	$50	$37,500			$290,000	$23,000		Operator assumed 2 hours per day, 7 days per week.
Power and Iron Costs	530	1000 GAL	$0.33	$200			$2,000	$160		Cost per 1000 gallons treated.
PACT SYSTEM - PHENOL/ORGANICS REMOVAL										Phenol and organics removal.
Annual Report	1	LS	$10,000	$10,000			$77,000	$6,200		
Sampling, Analysis, Reporting	30	SAMPLE	$500	$15,000			$110,000	$8,800		
Residual Transport and Disposal	1.3	TON	$100	$130			$1,000	$80	BARR	Disposal of Sludge in a Subtitle D Landfill (1/60 of quantity for 0-5 yea
Labor for Operation Optimization	750	HR	$50	$37,500			$290,000	$23,000		Operator assumed 2 hours per day, 7 days per week.
Power and Chemical Costs	365	DAY	$24	$9,000			$69,000	$5,500		
PACT SYSTEM - AMMONIA REMOVAL										Ammonia nitrification and denitrification (90%).
Annual Report	1	LS	$10,000	$10,000			$80,000	$6,400		
Sampling, Analysis, Reporting	30	SAMPLE	$500	$15,000			$110,000	$8,800		
Residual Transport and Disposal	1.3	TON	$100	$130			$1,000	$80	BARR	Disposal of Sludge in a Subtitle D Landfill (1/60 of quantity for 0-5 yea
Labor for Operation Optimization	750	HR	$50	$38,000			$290,000	$23,000		Operator assumed 2 hours per day, 7 days per week.
Power and Chemical Costs	365	DAY	$41	$15,000			$110,000	$8,800		
Carbon Source Addition for Denitrification	365	DAY	$25	$9,100			$70,000	$5,600		
Groundwater Monitoring	160	SAMPLE	$1,000	$160,000			$1,200,000	$96,000		
SUBTOTAL WATER TREATMENT OM&R COSTS (years 11-30)							$3,300,000	$260,000		
TREATMENT EQUIPMENT (years 11-30)										
Replace Wells (every 10 years)	2	WELL	$25,000	$50,000		2018	$19,000	$1,500		
Pipes, Pumps, and Equipment	1	LS	$2,000	$2,000			$15,000	$1,200	BARR	1% of equipment capital cost, due to lower flow.
Electrochemical Precipitation Equipment	1	LS	$3,200	$3,200			$24,000	$1,900	BARR	2% of equipment capital cost, due to lower flow.
PACT System Equipment	1	LS	$2,400	$2,400			$18,000	$1,400	BARR	0.4% of equipment capital cost, due to lower flow.
PACT System Equipment - Ammonia Removal	1	LS	$4,400	$4,400			$34,000	$2,700	BARR	0.4% of equipment capital cost, due to lower flow.
SUBTOTAL TREATMENT EQUIPMENT M&R COSTS (years 11-30)							$110,000	$9,000		
MONITORED NATURAL ATTENUATION										
Groundwater Monitoring	160	SAMPLE	$1,000	$160,000			$2,500,000	$160,000		
Data Evaluation/Modeling	1	LS	$10,000	$10,000			$150,000	$10,000	BARR	
Admin, Inspection, Annual Report	1	LS	$50,000	$50,000			$770,000	$50,000	BARR	
Five Year Review	1	LS	$60,000			2003	$60,000	$3,900		
Regulatory Oversight	1	LS	$10,000	$10,000			$150,000	$10,000	BARR	
SUBTOTAL MONITORED NATURAL ATTENUATION							$3,600,000	$230,000		
SUBTOTAL OM&R COSTS							$18,300,000	$2,000,000		
CONTINGENCY [3] (15%)							$2,700,000	$300,000		
ESTIMATED TOTAL OM&R COSTS							$21,000,000	$2,300,000		

NOTES:
[1] Includes costs through completion of treatment and disposal.
[2] Unit direct cost includes labor, materials, equipment, overhead, and profit.
[3] Calculated as Contingency Multiplier times Subtotal Direct Costs
[4] Present Worth values based on a net discount rate of 5% over 30 years

Table 5-C-44
Waukegan Manufactured Gas & Coke Plant Site
Remediation Contractor Capital Costs
Cost Estimate Details

Alternative 3: Removal
Vadose Zone Soil
Option 3A: Treatment
High Volume

ITEM	ESTIMATED QUANTITY	UNIT	UNIT DIRECT COST [1]	ITEM TOTAL DIRECT COST		SOURCE	COMMENTS
GENERAL REQUIREMENTS							
Submittals	1	LS	$20,000	$20,000		BARR	Includes contractor preparation of submittals which include work plans, QA plans, drawings, etc
Office	7	MO	$900	$6,300		MEANS	Rental of 2 - 50' x 12' trailer w/ AC
Mobilization	1	LS	$878,600	$878,600		BARR	10% of construction costs, does not include disposal
Demobilization and Decontamination	1	LS	$439,300	$439,300		BARR	5% of construction costs, does not inclued disposal
Utilities	7	MO	$600	$4,200		BARR	Estimate for FAX, telephone, toilets, heat, electricity, water, trash
Potable Water	7	MO	$800	$5,600		BARR	Includes delivered bottled water at 150 ga/week and rental of two coolers
SUBTOTAL GENERAL REQUIREMENTS:					$1,354,000		
SITE WORK							
Connect Utilities	1	LS	$5,000	$5,000		BARR	Includes connection of telephone and electricity to offices
Runon/runoff Control	1	LS	$10,000	$10,000		BARR	Install berms, silt fence, drainage ditches
Clear, Grub, and Subgrade Preparation	11.0	AC	$4,500.00	$49,440		MEANS	Clear & Grub brush, including stumps (assume half of site
Dust Control	7	MO	$4,000	$28,000		BARR	Labor and equipment for 2 hrs/day
Ambient Air Monitoring	7	MO	$15,000	$105,000		BARR	Estimate for monitoring from 3 sampling stations for metals, VOCs, particulates
Vehicle Decontamination Pad	1	LS	$4,000	$4,000		BARR	Construct a lined treatment decon area.
Vehicle Decontamination	7	MO	$5,000	$35,000		BARR	Cost for steam cleaning and operator for decon of all vehicles and equipment leaving the site
Personal Decontamination	7	MO	$1,900	$13,300		HAZCON	18'x24' trailer with negative air and 4 showers. Includes transportation
Water Storage Tanks	7	MO	$5,000	$35,000		BARR	Assume 2 Baker tanks
Access Improvements, Relocate Fence	1	LS	$10,000	$10,000		BARR	Site Improvements
SUBTOTAL SITE WORK:					$295,000		
EXCAVATION, TREATMENT, DISPOSAL, AND BACKFILL							
PAH REMEDIATION ZONE							
Set Up Processing and Stockpile Area	1	LS	$100,000	$100,000		BARR	Concrete pad for soil processing equipment, asphalt pad, concrete walls for staging
Strip and Stockpile Overburder	8,900	CY	$3	$26,700		BARR	Assume 6" Overburden in excavation areas (assume half of site)
Remove Existing Asphalt	7,200	SY	$5	$36,000		MEANS	OMC Driveway (South of Site)
Asphalt Disposal	1,800	CY	$30	$54,000		BARR	Recycle
Excavate Soil, Separate PAH Material, and							
Segregate Debris	29,300	CY	$20	$586,000		BARR	14,900 CY of tar & oily soil, 14,400 cy of overburden
Soil Mixing and Loading	33,500	Ton	$40	$1,340,000		BARR	Screening to segregate debris and mixing with coal (50% by wt) and other on-site soil to render non-hazardou
Sampling and Testing Processed Material	33,500	Ton	$10	$335,000		BARR	TCLP analysis
Load and Haul Processed Material to Power Plant	33,500	Ton	$60	$2,010,000		Kipin	Illinois Power, Baldwin power plant near East St. Louis
Thermal Treatment	33,500	Ton	$50	$1,675,000		Kipin	
Clean Debris	4,400	Ton	$20	$88,000		BARR	Debris consists of bricks, rebar, concerete,timber, and pipe; assume 10% debris by weigh
Load and Haul Debris to Local Landfill	4,400	Ton	$10	$44,000		BARR	
Debris Disposal at Landfill	4,400	Ton	$20	$88,000		BARR	
Dewatering, Pre-Treatment, and Disposal							
of Water During Excavation	2,800	1,000 Gal	$400	$1,120,000		BARR	Treatment through treatment system ($0.30/gal), discharge to POTW ($0.10/gal)
ARSENIC REMEDIATON ZONE							
Excavate Soil and Segregate Debris	7,200	CY	$20	$144,000		BARR	
Soil Stabilization and Stockpiling	10,800	Ton	$80	$864,000		BARR	
Sampling and Testing Processed Material	10,800	Ton	$10	$108,000		BARR	TCLP analysis
BACKFILL							
Backfill and Compact Stabilized Material	8,700	CY	$15	$130,500		BARR	
Load, Haul, Backfill, and Compact Soil from							
Designated Stockpile and Overburder	19,400	CY	$5	$97,000		BARR	
Backfill from Off-Site Source	9,900	CY	$12	$118,800		BARR	Includes $10/cy for material and delivery to site and $2/cy for installatior
SUBTOTAL EXCAVATION, TREATMENT, DISPOSAL, AND BACKFILL					$8,965,000		

Table 5-C-44 (continued)
Waukegan Manufactured Gas & Coke Plant Site
Remediation Contractor Capital Costs
Cost Estimate Details

Alternative 3: Removal
Vadose Zone Soil
Option 3A: Treatment
High Volume

ITEM	ESTIMATED QUANTITY	UNIT	UNIT DIRECT COST [1]	ITEM TOTAL DIRECT COST		SOURCE	COMMENTS
PHYTOREMEDIATION CAPPING							
SUBGRADE PREPARATION							
Soil Sampling and Analysis	1	LS	$5,000	$5,000		BARR	Nutrient content, compaction, salts, pH
Misc. Grading, Establish Drainage	1	LS	$10,000	$10,000		BARR	
Deep Tilling, Harrow	22	AC	$500.00	$11,000		BARR	Seedbed Preparation
6 inch layer of fill	17,725	CY	$12.00	$213,000		BARR	6" fill layer for phytoremediation cap area
ESTABLISH VEGETATION (3 ZONES)							
OILY ZONE							
Plant Trees	1,200	EA	$140	$168,000		BARR	Mulberry trees planted 15 ft on center
Organic Matter	300	CY	$50	$15,000		BARR	To establish tree growth
Plant Grass	261,400	EA	$1	$261,000		BARR	Grass plugs planted 1ft on center
Nurse Crop	180	LB	$30	$5,000		BARR	Non-competitive species (oats or wheat) to provide immediate erosion protection
MODERATELY CONTAMINATED ZONE							
Plant Grass	347,900	EA	$1	$348,000		BARR	Grass plugs planted 1ft on center
Nurse Crop	240	LB	$30	$7,000		BARR	Non-competitive species (oats or wheat) to provide immediate erosion protection
LOW CONTAMINATED ZONE							
Seed	8	AC	$4,000	$32,000		BARR	Grass seed
Hydromulch	8	AC	$1,000	$8,000		BARR	Erosion protection
MISCELLANEOUS							
Re-align Storm Sewer	500	LF	$70	$35,000		BARR	Includes restoration of lawn, parking lot, and manholes
De-watering/Pre-treatment, Disposal of Water During							
Storm Sewer Work	1	LS	$20,000	$20,000		BARR	Treatment through treatment system ($0.30/gal), discharge to POTW ($0.10/gal)
Abandon Monitoring Wells	4	EA	$3,000	$12,000		BARR	MW-9S,D: MW-7S,D
SUBTOTAL PHYTOREMEDIATION CAPPING:					$1,150,000		
SITE RESTORATION							
Restore Asphalt							OMC Driveway (South of Site)
Aggregate Subbase	970	CY	$15	$14,550		BARR	
Prepare and Roll Subbase	2,900	SY	$1	$2,900		MEANS	
Asphalt Wear Course	2,900	SY	$8	$23,200		MEANS	
Misc. Grading, Establish Drainage,							
Re-spread Topsoil	1	LS	$10,000	$10,000		BARR	
SUBTOTAL SITE RESTORATION:					$51,000		
ESTIMATED TOTAL FIELD COST				$11,815,000			
ESTIMATED TOTAL FIELD COST, EXCLUDING DISPOSAL				$10,140,000			
Bonds (3%)				$304,000			Does not include Disposal Costs for PAH Remediation Zone material.
Insurance (2%)				$203,000			Does not include Disposal Costs for PAH Remediation Zone material.
Contingencies (15%)				$1,772,000 [2]			
ESTIMATED TOTAL CONTRACTOR CONSTRUCTION COST:					$14,090,000		

NOTES:
[1] Unit direct cost includes labor, materials, equipment, overhead, and profit.
[2] Calculated as Contingency Multiplier times Estimated Total Field Cost

Table 5-C-45
Waukegan Manufactured Gas & Coke Plant Site
Non-Contractor Capital Costs
Cost Estimate Details

Alternative 3: Removal
Vadose Zone Soil
Option 3A: Treatment
High Volume

ITEM	ESTIMATED QUANTITY	UNIT	UNIT DIRECT COST [1]	ITEM TOTAL DIRECT COST		SOURCE	COMMENTS
Remedial Design Investigation							
Arsenic Stabilization Treatability Study	1	LS	$30,000	$30,000		BARR	
Soil TCLP Analyses	1	LS	$5,000	$5,000		BARR	
Regulatory Oversight	7	MO	$22,500	$157,500		BARR	
Design	1	LS	$250,000	$250,000		BARR	Includes Work Plan, Design, Construction QAPP, Remedial Action, PHASP, and meetings
Permits/Permitting Assistance	1	LS	$100,000	$100,000			
Engineering Services During Remedial Action	7	MO	$15,000	$105,000		BARR	Includes meetings, design scope changes, etc
Construction Documentation							
Field engineering/construction observation	7	MO	$25,000	$175,000		BARR	Includes monitoring daily field activities during construction
Construction documentation report	1	LS	$55,000	$55,000		BARR	Final report - Includes data, statistical clean-up verification analysis, post-remedy soil management plan
Material testing	1	LS	$203,000	$203,000		BARR	2% of construction costs
SUBTOTAL NON-CONTRACTOR COSTS					$1,081,000		
CONTINGENCY (15%)					$162,000 [2]		

ESTIMATED TOTAL NON-CONTRACTOR CAPITAL COST: $1,240,000

NOTES:
[1] Unit price includes labor, materials, and equipment
[2] Calculated as Contingency Multiplier times Subtotal Non-Contractor Direct Costs

Table 5-C-46
Waukegan Manufactured Gas & Coke Plant Site
Operation, Maintenance, and Repair Costs
Cost Estimate Details

Alternative 3: Removal
Vadose Zone Soil
Option 3A: Treatment
High Volume

ITEM	ESTIMATED QUANTITY	UNIT	UNIT DIRECT COST [1]	ITEM TOTAL DIRECT COST	FUTURE ITEM TOTAL DIRECT COST	YEAR FUTURE COST OCCURS	PRESENT WORTH OF DIRECT COST[2]	EQUIVALENT ANNUAL COST[2]	SOURCE	COMMENTS
Administration, Inspection, Annual Report	1	LS	$15,000	$15,000			$231,000	$15,000	BARR	
Analysis Review (every 5 years)	1	LS	$11,000			2002	$31,000	$2,000	BARR	
Regulatory Oversight	1	LS	$11,000	$11,000			$169,000	$11,000	BARR	
Maintain Phytoremediation Cover										
Maintenance (first two years)	1	LS	$25,000				$46,485	$3,026	BARR	Includes monthly mowing, spraying for weeds, landfill
Maintenance (year three through four)	1	LS	$15,000				$25,298	$1,647	BARR	grass clippings
Maintenance (after year four)	1	LS	$10,000				$118,266	$7,699	BARR	
Replace Trees (first year)	240	EA	$140	$33,600			$32,001	$2,083	BARR	Replace 20% of trees
Replace Trees (second year)	120	EA	$140	$16,800			$15,238	$992	BARR	Replace 10% of trees
Replace Grass (first year)	60,900	EA	$1	$60,900			$58,001	$3,776	BARR	Replace 10% of grass plugs
Watering (first year)	1	LS	$20,000	$20,000			$19,048	$1,240	BARR	
Bi-weekly Inspection (first year)	48	HR	$50	$2,400			$2,286	$149	BARR	Bi-weekly inspection (4-hrs per inspection) for 6 months
Monthly Inspection (after first year)	24	HR	$50	$1,200			$17,304	$1,126	BARR	Weekly inspection (4-hrs per inspection) for 6 months
Folage/Berry Analysis (first two years)	1	LS	$6,000	$6,000			$11,156	$726	BARR	Assumes 10 samples/month at $100/sample for 6 months
Folage/Berry Analysis (after year two)	1	LS	$3,000	$3,000			$40,539	$2,639	BARR	Assumes 5 samples/month at $100/sample for 6 months
SUBTOTAL OM&R COSTS							$817,000	$53,000		
CONTINGENCY (15%)							$123,000	$8,000 [3]		
ESTIMATED TOTAL OPERATION, MAINTENANCE, AND REPAIR COST:							$940,000	$61,000		

NOTES:
[1] Unit price includes labor, materials, and equipment.
[2] Present Worth values based on a net discount rate of 5% over 30 years
[3] Calculated as Contingency Multiplier times Subtotal Non-Contractor Direct Costs

Table 5-C-47
Waukegan Manufactured Gas & Coke Plant Site
Remediation Contractor Capital Costs
Cost Estimate Details

Alternative 3: Removal
Vadose Zone Soil
Option 3B: Disposal
High Volume

ITEM	ESTIMATED QUANTITY	UNIT	UNIT DIRECT COST [1]	ITEM TOTAL DIRECT COST		SOURCE	COMMENTS
GENERAL REQUIREMENTS							
Submittals	1	LS	$20,000	$20,000		BARR	Includes contractor preparation of submittals which include work plans, QA plans, drawings, etc
Office	7	MO	$900	$6,300		MEANS	Rental of 2 - 50' x 12' trailer w/ AC
Mobilization	1	LS	$707,350	$707,350		BARR	10% of construction costs, does not include disposal
Demobilization and Decontamination	1	LS	$353,675	$353,675		BARR	5% of construction costs, does not inclued disposal
Utilities	7	MO	$600	$4,200		BARR	Estimate for FAX, telephone, toilets, heat, electricity, water, trash
Potable Water	7	MO	$800	$5,600		BARR	Includes delivered bottled water at 150 ga/week and rental of two coolers
SUBTOTAL GENERAL REQUIREMENTS:					$1,097,000		
SITE WORK							
Connect Utilities	1	LS	$5,000	$5,000		BARR	Includes connection of telephone and electricity to offices
Runon/runoff Control	1	LS	$10,000	$10,000		BARR	Install berms, silt fence, drainage ditches
Clear, Grub, and Subgrade Preparation	11.0	AC	$4,500.00	$49,400		MEANS	Clear & Grub brush, including stumps (assume half of site
Dust Control	7	MO	$4,000	$28,000		BARR	Labor and equipment for 2 hrs/day
Ambient Air Monitoring	1	MO	$15,000	$15,000		BARR	Estimate for monitoring from 3 sampling stations for metals, VOCs, particulates
Vehicle Decontamination Pad	1	LS	$4,000	$4,000		BARR	Construct a lined treatment decon area.
Vehicle Decontamination	7	MO	$5,000	$35,000		BARR	Cost for steam cleaning and operator for decon of all vehicles and equipment leaving the site
Personal Decontamination	7	MO	$1,900	$13,300		HAZCON	18'x24' trailer with negative air and 4 showers. Includes transportation
Water Storage Tanks	7	MO	$5,000	$35,000		BARR	Assume 2 Baker tanks
Access Improvements, Relocate Fence	1	LS	$10,000	$10,000		BARR	Site Improvements
SUBTOTAL SITE WORK					$205,000		
EXCAVATION, DISPOSAL, AND BACKFILL							
PAH REMEDIATION ZONE							
Strip and Stockpile Overburden	8,900	CY	$3	$26,700		BARR	Assume 6" Overburden Across Site
Remove Existing Asphalt	7,200	SY	$5	$36,000		MEANS	OMC Driveway (South of Site)
Asphalt Disposal	1,800	CY	$30	$54,000		BARR	Recycle, Includes transportation and disposal
Excavate Soil, Separate PAH Material	29,300	CY	$20	$586,000		BARR	14,900 CY of tar & oily soil, 14,400 cy of overburden
Soil Mixing and Loading	33,500	Ton	$40	$1,340,000		BARR	Mix tar with oily soil to allow for handling, loading, and unloading
Sampling and Testing	33,500	Ton	$10	$335,000		BARR	
Load and Haul PAH Material	33,500	Ton	$33	$1,105,500		PDC	
Disposal at RCRA Subtitle C Landfill	33,500	Ton	$75	$2,512,500		PDC	Disposal in Peoria, IL
Dewatering, Pre-Treatment, and Disposal of Water During Excavation	2,800	1,000 Gal	$400	$1,120,000		BARR	Treatment through treatment system ($0.30/gal), discharge to POTW ($0.10/gal)
ARSENIC REMEDIATION ZONE							
Set Up Segregation Area and Equipment	1	LS	$100,000	$100,000		BARR	Concrete pad for soil processing equipment, asphalt pad, concrete walls for staging
Excavate Soil and Segregate Debris	7,200	CY	$20	$144,000		BARR	
Sampling and Testing	10,800	Ton	$10	$108,000		BARR	
Load and Haul Arsenic Material	10,800	Ton	$33	$356,400		PDC	
Disposal at RCRA Subtitle C Landfill	10,800	Ton	$100	$1,080,000		PDC	Includes stabilization of Arsenic and disposal in Peoria, IL
Clean Debris	1,080	Ton	$20	$21,600		BARR	Debris consists of bricks, rebar, concerete,timber, and pipe; assume 10% debris by weigh
Load and Haul Debris to Local Landfill	1,080	Ton	$10	$10,800		BARR	
Debris Disposal at Landfill	1,080	Ton	$20	$21,600		BARR	
BACKFILL							
Load, Haul, Backfill, and Compact Soil from Designated Stockpile and Overburden	19,400	CY	$5	$97,000		BARR	
Backfill from Off-Site Source	17,100	CY	$12	$205,200		BARR	Includes $10/cy for material and delivery to site and $2/cy for installation
SUBTOTAL EXCAVATION, TREATMENT, DISPOSAL, AND BACKFILL:					$9,260,000		

Table 5-C-47 (continued)
Waukegan Manufactured Gas & Coke Plant Site
Remediation Contractor Capital Costs
Cost Estimate Details

Alternative 3: Removal
Vadose Zone Soil
Option 3B: Disposal
High Volume

ITEM	ESTIMATED QUANTITY	UNIT	UNIT DIRECT COST [1]	ITEM TOTAL DIRECT COST		SOURCE	COMMENTS
PHYTOREMEDIATION CAPPING							
SUBGRADE PREPARATION							
Soil Sampling and Analysis	1	LS	$5,000	$5,000		BARR	Nutrient content, compaction, salts, pH
Misc. Grading, Establish Drainage	1	LS	$10,000	$10,000		BARR	
Deep Tilling, Harrow	22	AC	$500.00	$11,000		BARR	Seedbed Preparation
6 inch layer of fill	17,725	CY	$12.00	$213,000		BARR	6" fill layer for phytoremediation cap area
ESTABLISH VEGETATION (3 ZONES)							
OILY ZONE							
Plant Trees	1,200	EA	$140	$168,000		BARR	Mulberry trees planted 15 ft on center
Organic Matter	300	CY	$50	$15,000		BARR	To establish tree growth
Plant Grass	261,400	EA	$1	$261,000		BARR	Grass plugs planted 1 ft on center
Nurse Crop	180	LB	$30	$5,400		BARR	Non-competitive species (oats or wheat) to provide immediate erosion protection
MODERATELY CONTAMINATED ZONE							
Plant Grass	347,900	EA	$1	$348,000		BARR	Grass plugs planted 1 ft on center
Nurse Crop	240	LB	$30	$7,000		BARR	Non-competitive species (oats or wheat) to provide immediate erosion protection
LOW CONTAMINATED ZONE							
Seed	8	AC	$4,000	$32,000		BARR	Plant grass
Hydromulch	8	AC	$1,000	$8,000		BARR	Erosion protection
MISCELLANEOUS							
Re-align Storm Sewer	500	LF	$70	$35,000		BARR	
De-watering/Pre-treatment, Disposal of Water During							
Storm Sewer Work	1	LS	$20,000	$20,000		BARR	Treatment through treatment system ($0.30/gal), discharge to POTW ($0.10/gal)
Abandon Monitoring Wells	4	EA	$3,000	$12,000		BARR	MW-9S,D: MW-7S,D
SUBTOTAL PHYTOREMEDIATION CAPPING:					$1,150,000		
SITE RESTORATION							
Restore Asphalt							OMC Driveway (South of Site)
Aggregate Subbase	970	CY	$15	$14,550		BARR	
Prepare and Roll Subbase	2,900	SY	$1	$2,900		MEANS	
Asphalt Wear Course	2,900	SY	$8	$23,200		MEANS	
Misc. Grading, Establish Drainage,							
Re-spread Topsoil	1	LS	$10,000	$10,000		BARR	
SUBTOTAL SITE RESTORATION:					$51,000		
ESTIMATED TOTAL FIELD COST				$11,763,000			
ESTIMATED TOTAL FIELD COST, EXCLUDING DISPOSAL				$8,170,500			
Bonds (3%)				$245,000			Does not include Disposal Costs for PAH Remediation Zone material.
Insurance (2%)				$163,000			Does not include Disposal Costs for PAH Remediation Zone material.
Contingencies (15%)				$1,764,000 [2]			
ESTIMATED TOTAL CONTRACTOR CONSTRUCTION COST:				$13,935,000			

NOTES:
[1] Unit direct cost includes labor, materials, equipment, overhead, and profit.
[2] Calculated as Contingency Multiplier times Estimated Total Field Cos

Table 5-C-48
Waukegan Manufactured Gas & Coke Plant Site
Non-Contractor Capital Costs
Cost Estimate Details

Alternative 3: Removal
Vadose Zone Soil
Option 3B: Disposal
High Volume

ITEM	ESTIMATED QUANTITY	UNIT	UNIT DIRECT COST [1]	ITEM TOTAL DIRECT COST		SOURCE	COMMENTS
Remedial Design Investigation							
Soil TCLP Analyses	1	LS	$5,000	$5,000		BARR	
Regulatory Oversight	7	MO	$22,500	$157,500		BARR	
Design	1	LS	$250,000	$250,000		BARR	Includes Work Plan, Design, Construction QAPP, Remedial Action, PHASP, and meetings
Permits/Permitting Assistance	1	LS	$100,000	$100,000			
Engineering Services During Remedial Action	7	MO	$15,000	$105,000		BARR	Includes meetings, design scope changes, etc
Construction Documentation							
Field engineering/construction observation	7	MO	$25,000	$175,000		BARR	Includes monitoring daily field activities during construction
Construction documentation report	1	LS	$55,000	$55,000		BARR	Final report - Includes data, statistical clean-up verification analysis, post-remedy soil management plan
Material testing	1	LS	$163,000	$163,000		BARR	2% of construction costs
SUBTOTAL NON-CONTRACTOR COSTS					$1,011,000		
CONTINGENCY (15%)					$152,000	[2]	
ESTIMATED TOTAL NON-CONTRACTOR CAPITAL COST:					$1,160,000		

NOTES:
[1] Unit price includes labor, materials, and equipment
[2] Calculated as Contingency Multiplier times Subtotal Non-Contractor Direct Costs

Table 5-C-49
Waukegan Manufactured Gas & Coke Plant Site
Operation, Maintenance, and Repair Costs
Cost Estimate Details

Alternative 3: Removal
Vadose Zone Soil
Option 3B: Disposal
High Volume

ITEM	ESTIMATED QUANTITY	UNIT	UNIT DIRECT COST [1]	ITEM TOTAL DIRECT COST	FUTURE ITEM TOTAL DIRECT COST	YEAR FUTURE COST OCCURS	PRESENT WORTH OF DIRECT COST [2]	EQUIVALENT ANNUAL COST [2]	SOURCE	COMMENTS
Administration, Inspection, Annual Report	1	LS	$15,000	$15,000			$231,000	$15,000	BARR	
Analysis Review (every 5 years)	1	LS	$11,000			2002	$31,000	$2,000	BARR	
Regulatory Oversight	1	LS	$11,000	$11,000			$169,000	$11,000	BARR	
Maintain Phytoremediation Cover										
Maintenance (first two years)	1	LS	$25,000				$46,485	$3,026	BARR	Includes monthly mowing, spraying for weeds, landfill
Maintenance (year three through four)	1	LS	$15,000				$25,298	$1,647	BARR	grass clippings
Maintenance (after year four)	1	LS	$10,000				$118,266	$7,699	BARR	
Replace Trees (first year)	240	EA	$140	$33,600			$32,001	$2,083	BARR	Replace 20% of trees
Replace Trees (second year)	120	EA	$140	$16,800			$15,238	$992	BARR	Replace 10% of trees
Replace Grass (first year)	60,900	EA	$1	$60,900			$58,001	$3,776	BARR	Replace 10% of grass plugs
Watering (first year)	1	LS	$20,000	$20,000			$19,048	$1,240	BARR	
Bi-weekly Inspection (first year)	48	HR	$50	$2,400			$2,286	$149	BARR	Bi-weekly inspection (4-hrs per inspection) for 6 months
Monthly Inspection (after first year)	24	HR	$50	$1,200			$17,304	$1,126	BARR	Weekly inspection (4-hrs per inspection) for 6 months
Folage/Berry Analysis (first two years)	1	LS	$6,000	$6,000			$11,156	$726	BARR	Assumes 10 samples/month at $100/sample for 6 months
Folage/Berry Analysis (after year two)	1	LS	$3,000	$3,000			$40,539	$2,639	BARR	Assumes 5 samples/month at $100/sample for 6 months
SUBTOTAL OM&R COSTS							$817,000	$53,000		
CONTINGENCY (15%)							$123,000	$8,000 [3]		
ESTIMATED TOTAL OPERATION, MAINTENANCE, AND REPAIR COST							$940,000	$61,000		

NOTES:
[1] Unit price includes labor, materials, and equipment.
[2] Present Worth values based on a net discout rate of 5% over 30 years
[3] Calculated as Contingency Multiplier times Subtotal Non-Contractor Direct Costs

Table 5-C-50
Waukegan Manufactured Gas & Coke Plant Site
Remediation Contractor Capital Costs
Cost Estimate Details [1]

Alternative 3: Removal
Groundwater
High Cost

ITEM	ESTIMATED QUANTITY	UNIT	UNIT DIRECT COST [2]	ITEM TOTAL DIRECT COST	SOURCE	COMMENTS
GENERAL REQUIREMENTS						
Submittals	1	LS	$20,000	$20,000	BARR	Includes contractor prepartion of submittals which incl. work plans, QA plans, drawings, etc.
Offices	4	MO	$900	$3,600	MEANS	
Mobilization	1	LS	$420,000	$420,000	BARR	General contractor mobe for site work, excavation, water treatment, restoration (10% of cost)
Decontamination and Demobilization	1	LS	$210,000	$210,000	BARR	General contractor demobe for site work, excavation, water treatment, restoration (5% of cost)
Utilities	4	MO	$600	$2,400	BARR	Estimate for FAX, telephone, toilets, heat, electricity, water, trash
Potable Water	4	MO	$800	$3,200	MEANS	
SUBTOTAL GENERAL REQUIREMENTS				$660,000		
SITE WORK						
Dust Control	2	MO	$4,000	$8,000	BARR	Labor and equipment for 2 hrs/day
Ambient Air Monitoring	2	MO	$15,000	$30,000	BARR	Estimate for monitoring from 3 sampling stations for metals, VOCs, particulates.
Vehicle Decontamination	2	MO	$5,000	$10,000	BARR	Cost for steam cleaning and operator for decon of all vehicles and equipment leaving the site.
Personal Decontamination	2	MO	$1,900	$3,800	HAZCON	18' X 24' trailer with negative air and 4 showers. Includes transportation.
SUBTOTAL SITE WORK				$52,000		
GROUNDWATER EXTRACTION / INFILTRATION						
Groundwater pump	4	EA	$12,000	$48,000	NEEP SYSTEMS	EconoPump Multi-well jet system, one unit per cell.
Groundwater pump controls	4	EA	$20,000	$80,000		Power supply, controls, and plumbing
Piping - 24" diameter corrugated PEP	1800	LF	$35	$63,000	BARR	Conduit to house piping
Install manholes	10	EA	$2,500	$25,000	BARR	Manholes along conduit
Piping - 1" diameter	54000	LF	$2	$110,000	BARR	1" diameter polyethylene piping between wells and pump, and to reinjection cells.
36" RCP Under Road	260	LF	$75	$20,000	BARR	Casing pipe for well lines. Includes open cut and asphalt restoration
Install monitoring wells	20	WELL	$5,000	$100,000	BARR	Additional groundwater monitoring.
SUBTOTAL GROUNDWATER EXTRACTION / INFILTRATION				$450,000		
WATER TREATMENT - 60 GPM						
Utilities	1	LS	$30,000	$30,000	BARR	$15K power, $10K sewer, $5K water, telephone, etc.
Building for Treatment Equipment	3500	SF	$100	$350,000	MEANS	Warehouse/Storage building at 4000 square feet
HVAC for Treatment Building	3500	SF	$10	$35,000	MEANS	
Electrical for Treatment Building	3500	SF	$9	$32,000	MEANS	
Concrete Slab / Footings	300	CY	$500	$150,000	BARR	Assumes 12" thick slab
System Assembly	1000	HR	$50	$50,000	BARR	
Pipes, Pumps & Equip.	1	LS	$100,000	$100,000	BARR	
Total System Startup	400	HR	$100	$40,000	BARR	
Startup Sampling	100	SMPL	$1,000	$100,000	BARR	
Field Pilot Study						
Equipment - Andco	6	MO	$20,000	$120,000	BARR	Andco equipment rental.
Equipment - Zimpro PACT	6	MO	$25,000	$150,000	BARR	Zimpro equipment rental.
Transportation of Equipment	1	LS	$5,000	$5,000	BARR	Operator 24 hours per week at $60 per hour.
Operation	6	MO	$5,800	$35,000	BARR	Operator 24 hours per week at $60 per hour.
Sampling	430	SMPL	$1,000	$430,000	BARR	14 sampling events, 30 samples per event, plus 6 samples over first 2 weeks
Installation & Startup	200	HR	$100	$20,000	BARR	
Electrochemical Precipitation						
Equipment	1	LS	$160,000	$160,000	ANDCO	Arsenic removal.
Transportation of equipment	1	LS	$5,000	$5,000	ANDCO	
Installation & Startup	1	LS	$20,000	$20,000	BARR	Andco support for start-up.
Activated Sludge with PAC						
PACT System Equipment	1	LS	$900,000	$900,000	ZIMPRO	Phenol, organics, and partial ammonia removal
Transportation & Installation	1	LS	$290,000	$290,000	ZIMPRO	
SUBTOTAL WATER TREATMENT				$3,000,000		
SUBTOTAL CONTRACTOR DIRECT COST				$4,200,000		
BONDS (3%)				$130,000		
INSURANCE (2%)				$80,000		
CONTINGENCY [3] (15%)				$600,000		
ESTIMATED TOTAL CONTRACTOR CONSTRUCTION COST				$5,000,000		

NOTES:
[1] Includes costs through completion of treatment and disposal
[2] Unit direct cost includes labor, materials, equipment, overhead, and profit.
[3] Calculated as Contingency Multiplier times Subtotal Direct Costs

Table 5-C-51
Waukegan Manufactured Gas & Coke Plant Site　　　**Alternative 3: Removal**
Non-Contractor Capital Costs　　　**Groundwater**
Cost Estimate Details [1]　　　**High Cost**

ITEM	ESTIMATED QUANTITY	UNIT	UNIT DIRECT COST [2]	ITEM TOTAL DIRECT COST	SOURCE	COMMENTS
Remedial Design Investigation						
Groundwater monitoring wells	1	LS	$200,000	$200,000	BARR	Includes installation of 20 additional monitoring well nests, and geoprobe costs at $1200/day for 2 days
Groundwater sampling	1	LS	$50,000	$50,000	BARR	Sampling and analysis of 22 monitoring well nests and 6 geoprobes
Surface water sampling	1	LS	$100,000	$100,000	BARR	Includes 2 surface water sampling events at $50,000 each
Pilot Study						
Work Plan & Coordination	1	LS	$30,000	$30,000	BARR	Design.
Engineering Oversight	6	MO	$10,000	$60,000	BARR	Engineering oversight during pilot study.
Final Report	1	LS	$30,000	$30,000	BARR	Regulatory oversight during construction activities.
Design	1	LS	$250,000	$250,000	BARR	Includes work plan, treatment system and cell design, QA/QC plan, SHSP, and meetings
Bidding/Bidding Administration	1	LS	$30,000	$30,000	BARR	
Permits/Permitting Assistance	1	LS	$50,000	$50,000	BARR	
Regulatory Oversight	4	MO	$22,500	$90,000	BARR	Regulatory oversight during construction activities.
Engineering Services for Remedial Action	4	MO	$15,000	$60,000	BARR	Includes construction meetings, changes to plans and specifications, etc.
Field engineering/construction observation	4	MO	$25,000	$100,000	BARR	Includes monitoring daily field activities for 4 months.
H & S Monitoring/Air Monitoring	1	MO	$7,000	$7,000	BARR	Includes health and safety specialist.
Construction documentation report	1	LS	$45,000	$45,000	BARR	Final report
SUBTOTAL NON-CONTRACTOR COSTS				$1,100,000		

CONTINGENCY (15%) [3]　　　　　　　　　　　　　　　　　$165,000

| ESTIMATED TOTAL NON-CONTRACTOR CAPITAL COST | | | | $1,270,000 | | |

NOTES
[1] Includes costs through completion of treatment and disposal
[2] Unit direct cost includes labor, materials, equipment, overhead, and profit
[3] Calculated as Contingency Multiplier times Contractor Subtotal Direct Costs

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Table 5-C-52
Waukegan Manufactured Gas & Coke Plant Site Alternative 3: Removal
Operation, Maintenance, and Repair Costs Groundwater
Cost Estimate Details [1] High Cost

ITEM	ESTIMATED QUANTITY	UNIT	UNIT DIRECT COST [2]	ANNUAL ITEM TOTAL DIRECT COST	FUTURE ITEM TOTAL DIRECT COST	YEAR COST OCCURS	PRESENT WORTH OF DIRECT COST [4]	EQUIVALENT ANNUAL COST [4]	SOURCE	COMMENTS
TREATMENT CELLS										Four treatment cells installed and operated per year.
Sampling, Analysis, Reporting	1	LS	$200,000	$200,000			$1,500,000	$200,000	BARR	
Wellpoint Installation	120	WELL	$600	$72,000			$560,000	$72,000	MEANS	For one treatment cell: 10 pumping, 20 reinjection wells.
Additional Piping - 1" diameter	24000	LF	$2	$48,000			$370,000	$48,000	BARR	1" diameter polyethylene required for moving the treatment c
Repair, Maintenance	1	LS	$80,000	$80,000			$620,000	$80,000	BARR	Well and pump maintenance.
SUBTOTAL CELL OM&R COSTS							$3,100,000	$400,000		
Engineering Oversight	400	HR	$100	$40,000			$310,000	$40,000		
WATER TREATMENT										
Heating and Cooling of Treatment Building	1	LS	$40,000	$40,000			$310,000	$40,000		
ELECTROCHEMICAL PRECIPITATION										
Annual Report	1	LS	$10,000	$10,000			$77,000	$10,000		Arsenic removal.
Sampling, Analysis, Reporting	30	SAMPLE	$500	$15,000			$116,000	$15,000		
Residual Transport and Disposal	20	TON	$100	$2,000			$15,000	$2,000	BARR	Disposal of Sludge in a Subtitle D Landfill
Labor for Operation	3000	HR	$50	$150,000			$1,200,000	$150,000		Operator assumed 8 hours per day, 7 days per week.
Power and Iron Costs	32000	1000 GAL	$0.33	$11,000			$85,000	$11,000		Cost per 1000 gallons treated.
PACT SYSTEM										
Annual Report	1	LS	$15,000	$15,000			$120,000	$15,000		Phenol, organics, and partial ammonia removal.
Sampling, Analysis, Reporting	30	SAMPLE	$600	$18,000			$140,000	$18,000		
Residual Transport and Disposal	150	TON	$100	$15,000			$120,000	$15,000	BARR	Disposal of Sludge in a Subtitle D Landfill
Labor for Operation Optimization	3000	HR	$50	$150,000			$1,200,000	$150,000		Operator assumed 8 hours per day, 7 days per week.
Power and Chemical Costs	365	DAY	$220	$80,000			$620,000	$80,000		
Groundwater Monitoring	160	SAMPLE	$1,000	$160,000			$1,200,000	$160,000		
SUBTOTAL WATER TREATMENT OM&R COSTS							$5,500,000	$710,000		
TREATMENT EQUIPMENT										
Pipes, Pumps, and Equipment	1	LS	$10,000	$10,000			$77,000	$10,000	BARR	10% of equipment capital cost
Electrochemical Precipitation Equipment	1	LS	$32,000	$32,000			$250,000	$32,000	BARR	20% of equipment capital cost
PACT System Equipment	1	LS	$36,000	$36,000			$280,000	$36,000	BARR	4% of equipment capital cost
SUBTOTAL TREATMENT EQUIPMENT M&R COSTS							$600,000	$78,000		
MONITORED NATURAL ATTENUATION										
Groundwater Monitoring	160	SAMPLE	$1,000	$160,000			$2,460,000	$160,000		
Data Evaluation/Modeling	1	LS	$10,000	$10,000			$150,000	$10,000	BARR	
Admin, Inspection, Annual Report	1	LS	$50,000	$50,000			$770,000	$50,000	BARR	
Five Year Review	1	LS	$60,000			2003	$60,000	$4,000		
Regulatory Oversight	1	LS	$10,000	$10,000			$154,000	$10,000	BARR	
SUBTOTAL MONITORED NATURAL ATTENUATION							$3,600,000	$230,000		
SUBTOTAL OM&R COSTS							$12,800,000	$1,400,000		
CONTINGENCY [3] (15%)							$1,900,000	$210,000		
ESTIMATED TOTAL OM&R COSTS							$14,700,000	$1,600,000		

NOTES:
[1] Includes costs through completion of treatment and disposal
[2] Unit direct cost includes labor, materials, equipment, overhead, and profit.
[3] Calculated as Contingency Multiplier times Subtotal Direct Costs
[4] Present Worth values based on a net discount rate of 5% over 10 years

Appendix 5-D

Groundwater and Surface Water Modeling of Remedial Actions

Appendix 5-D

Groundwater and Surface Water Modeling of Remedial Actions

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Figure 5-D-24   Mass Flux Comparison for Ammonia Removal—Lake Discharge

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Appendix 5-D

Groundwater and Surface Water Modeling of Remedial Actions

Groundwater and contaminant transport modeling were performed to evaluate the hydrogeologic effects of the groundwater alternatives. Fate and transport modeling and surface water modeling were performed to estimate discharge of impacted groundwater to Lake Michigan, Waukegan Harbor, and the breakwater area. Fate and transport modeling and surface water modeling were performed for Alternative 1 (No Action), Alternative 2 (Containment), and Alternative 3 (Removal). Fate and transport modeling and surface water modeling were not conducted on Alternative 4 (Aquifer Restoration) because there is practically no discharge of groundwater to surface water in that alternative.

The SLAEM groundwater model was used for determining the hydrogeologic effects of the alternatives. The refined WCP site groundwater model, which was developed as part of the remedial investigation and was refined for the FS, was used as the base model upon which scenario modeling was conducted as part of this study. The refined WCP site groundwater model is described in Appendix 2-B.

The contaminant transport modeling was conducted using the program CONTRA. CONTRA utilizes the convolutional solution method (Maas, 1994). The program CONTRA employs an Eulerian contaminant transport approach where the velocity field is derived from an analytically computed flow regime (Fairbrother, 1992; Strack and Fairbrother, 1997). CONTRA is a transport module that is well suited for use with an analytic element model such as SLAEM (Strack, 1987, 1989). CONTRA is capable of addressing advection, classical dispersion, moving-front dispersion, classical retardation, rate-limited sorption, and first-order biological or radioactive decay. Detailed descriptions of the convolutional method used in CONTRA are in the attachment "Efficient Approximate Solutions to 1-D Dispersive Transport Equations."

For this study, CONTRA was used to model the transport of arsenic, ammonia, and phenols to three surface water discharge areas for Alternatives 1, 2, and 3. The surface discharge areas were defined based on surface water standards and general groundwater flow patterns at the site. These three defined discharge areas include: 1) Lake Michigan north of the breakwater pier, 2) the breakwater area between the north harbor wall and the breakwater pier, and 3) Waukegan Harbor. These areas are shown on Figure 5-D-1.

Mass fluxes were determined for each of the three contaminants for each of the three defined discharge areas. The mass flux over time to each area was determined for each remedial alternative. The mass flux estimates presented here were developed using the SLAEM groundwater flow model and the CONTRA transport model. The groundwater discharge lines along Waukegan Harbor, and breakwater area, and Lake Michigan were subdivided into 5-foot segments. Concentrations were obtained from CONTRA computed values and evaluated at each elemental segment using the computer program "Surfer." Discharges for each segment were computed from the refined groundwater model. Combining concentrations with the discharges, computed mass loadings were determined for each segment. Integration of the unit mass loadings provided mass loading values for Waukegan Harbor, the breakwater area, and Lake Michigan (Figure 5-D-2). The initial spatial distribution of concentration before groundwater treatment is shown on Figures 5-D-3, 5-D-4, and 5-D-5 for arsenic, phenols, and ammonia, respectively. The spatial distribution of concentrations after treatment for arsenic, phenols, and ammonia is shown on Figures 5-D-6, 5-D-7 and 5-D-8, respectively.

As is typical of any groundwater transport modeling, several modeling assumptions were made. Some are inherent in the modeling method and some are necessary in order to define model parameters. The following is a list of assumptions used in this study:

1. The transport phenomena were limited to advection, classical dispersion, and classical retardation. Several factors cause this modeling to overestimate the mass flux discharging with the groundwater. While field evidence strongly suggests anaerobic biodegradation of organics where the plume is dilute (i.e., the upper fringe), estimating the effects of this sort of attenuation requires integration of several models, as is done in Appendix 5-E. Such biological activity (aerobic and/or anaerobic) would reduce the mass flux results but is not reflected in the mass flux modeling. The mass flux modeling also does not account for the progressive downward movement of the upper fringe of the high concentration zone at the base of the aquifer (see Appendix 5-E for an analysis of the influence of that effect on concentrations over time). This means that, although the zone of high concentrations gets thinner over time, the model assumes constant thickness. Thus, the tendency of the model to overestimate the mass flux increases with time.

2. It was assumed that arsenic behaves as a classical contaminant in that it does not sorb to the groundwater medium. Based on research (Wuolo, 1986), arsenic species (arsenate and arsenite) in an anoxic environment tend to sorb to the groundwater medium, dependent on the groundwater pH. The research included column tests of arsenic speciation through saturated soil conditions similar to the conditions present in the lower 5 feet of the aquifer at the site: low concentrations of oxygen in the

presence of the arsenic species arsenate and arsenite. The site average ratio of arsenite to arsenate is 66:1 and the pH in the lower portion of the aquifer ranges from 6.80 to 8.94 with an average of 8.08 across the site. This site information, interpreted in light of the research, suggests that little sorption of arsenate or arsenite species is expected above concentrations of 100 µg/L and 200 µg/L. Therefore, a retardation factor of 1 (i.e., no retardation) was used in modeling the transport of arsenic.

3. It was assumed that ammonia also behaves as a classical contaminant that does not sorb to the aquifer. Laboratory testing of the geologic composition of the aquifer material indicates that it is relatively clean with respect to clays, loams, and organic silts. The absence of these soil types indicates that any sorption of ammonia to the soil media is limited. It was deemed appropriate to treat ammonia as a non-sorbed substance based on available information on the site geology. Therefore, a retardation factor of 1 was used in modeling the transport of ammonia.

4. It was assumed the phenols behave as a classical sorptive contaminant. Based on numerous research studies, the sorption kinetics can be described by a Fruendlich isotherm. Based on published literature values for phenolic compounds, a partitioning coefficient of 27 was determined for phenol in groundwater. Therefore, using aquifer characteristics determined during the RI: a soil density of 1.7 g/ml, an aquifer porosity of 0.38, and an aquifer organic carbon content of 2 percent; a retardation factor of 3.4 was computed for modeling the transport of phenols.

5. Initial concentrations for arsenic, ammonia, and phenols over the site were assumed to be represented by the concentration contours presented in Section 2 of the FS (Conceptual Site Model). These concentrations were applied to the full bottom 5 feet of the aquifer, rather than attenuating with height above the base of the aquifer. This introduces a strong tendency for the model to overestimate the mass flux, especially for the dunes area of the beach, where the groundwater data show a significant decline in concentration with height above the base of the aquifer.

6. Base groundwater conditions (groundwater piezometric head, groundwater flow direction and discharge) assume conditions stated in the refined WCP site groundwater model described in Appendix 2-B.

7. The results presented here assume that modeled groundwater discharge occurs at water's edge (harbor and lake). No attempt was made to account for the mechanisms of migration, dispersion, sorption, and biological activity beneath Lake Michigan, the breakwater area, or in Waukegan Harbor.

In evaluating the following prediction results, the limited capability of fate and transport models must be considered. Therefore, predicted concentrations beyond few years should be viewed as approximations, suitable for comparative analyses. Furthermore, as these concentrations reach low levels, their time frames should be considered as relative, order-of magnitude estimates.

Alternative 1 (No Action)

Modeling a No Action case provides a baseline against which to compare the mass flux of arsenic, ammonia, and phenols for the other remedial alternatives.

Figure 5-D-9 shows the flow patterns and piezometric head distribution representative of the calibrated groundwater model. From the flow patterns, several localized groundwater divides are also presented. These divides correspond to the three surface water discharge areas.

Alternative 2 (Containment)

Modeling the Containment case provides a means to assess and characterize the affected groundwater flow regime and also to characterize the migration and transport of arsenic, ammonia, and phenols. This modeling evaluation was performed to assess the long-term migration of compounds following implementation of the groundwater treatment cell remedy. The modeling used a reduction in concentration in the cell treatment area for ammonia of 50 percent, for arsenic of 85 percent, and for phenols of 50 percent. Supplementary modeling was also performed to evaluate ammonia reductions in concentration of 0, 50, and 85 percent, as discussed below under Mass Flux Analysis. These reductions in concentration were applied in the area defined by the 20 mg/L concentration contour for arsenic. It was assumed that, in addition to no net infiltration in the slurry wall area and the stormwater detention pond area, revegetation of the remaining area reduced site infiltration to 50 percent of the base (No Action) infiltration rate. Figure 5-D-10 shows the portions of the site where infiltration was reduced to 50 percent (from 11.47 to 5.73 in./yr) by revegetation and to 0 percent (to 0 in./year) for the slurry wall and stormwater detention basin areas.

Figure 5-D-11 shows the predicted flow patterns and piezometric head distribution following construction of a containment cell and after operation of cell treatment system. The figure also shows localized groundwater divides based on the flow patterns.

Alternative 3 (Removal)

Modeling the Removal case provides a means to assess and characterize the affected groundwater flow regime and also to characterize the migration and transport of arsenic, ammonia, and phenols. This modeling evaluation was performed to assess the long-term migration of compounds following implementation of the groundwater treatment cell remedy. The modeling used a reduction in concentration in the cell treatment area for ammonia of 50 percent, for arsenic of 85 percent, and for phenols of 50 percent. Supplementary modeling was also performed to evaluate ammonia reductions in concentration of 0, 50, and 85 percent, as discussed below under Mass Flux Analysis. These reductions in concentration were applied in the area defined by the 20 µg/L concentration contour for arsenic. The phytoremediation cap is expected to reduce infiltration to 0 percent of the base infiltration rate. Figure 5-D-12 show the portions of the site where infiltration as reduced. Sensitivity modeling with respect to the effectiveness of a phytoremediation cap was also incorporated into this analysis. Two infiltration reduction cases were modeled: to 50 percent (from 11.47 to 5.73 in./yr) and to 0 percent (from 11.47 to 0.0 in./yr).

Figure 5-D-13 shows the predicted flow patterns and piezometric head distribution following operation of cell treatment systems, assuming the phytoremediation cap reduced infiltration to 50 percent. The figure also shows localized groundwater divides based on the flow patterns.

Figure 5-D-14 shows the predicted flow patterns and piezometric head distribution following operation of cell treatment systems, assuming the phytoremediation cap reduced infiltration to 0 percent. The figure also shows localized groundwater divides based on the flow patterns.

Mass Flux Analysis

Groundwater modeling and contaminant transport analyses were conducted for Alternative 1 (No Action), Alternative 2 (Containment), and two scenarios for Alternative 3 (Removal). Figures 5-D-15 through 5-D-23 summarize the mass flux time series of ammonia, arsenic, and phenols to Lake Michigan, the breakwater area, and Waukegan Harbor for each of the modeled remedial alternatives. Ammonia mass flux over time for Alternatives 1, 2 and 3 is shown in Figures 5-D-15, 5-D-16, and 5-D-17 to the lake, breakwater area, and harbor, respectively. Arsenic mass flux over time for Alternatives 1, 2 and 3 is shown in Figures 5-D-18, 5-D-19, and 5-D-20 to the lake, breakwater area, and harbor, respectively. Phenols mass flux over time for Alternatives 1, 2 and 3 is shown in Figures 5-D-21, 5-D-22, and 5-D-23 to the lake, breakwater area, and harbor, respectively.

The surface water quality for the computed peak mass fluxes for each remedy is shown in Tables 5-D-1 through 5-D-16. These calculated surface water concentrations are considered overestimates of the potential effects on surface water and are computed using the models presented in Appendix 2-D. The peak mass flux from the groundwater to each receiving water was used for each remedy to perform the analysis in tables 5-D-1 through 5-D-16. The analytical methodology is shown in detail in Appendix 2-D for the no action case. Tables 5-D-1 through 5-D-4 summarize the No Action alternative results for the harbor, longshore current zone, lake east of the site, and breakwater area. Tables 5-D-5 through 5-D-8 are for the Containment alternative. The ammonia removal from the groundwater treatment area was 50 percent for this model. Tables 5-D-9 through 5-D-12 are for the Removal alternative with no net infiltration (0% infiltration) over the capped area. Tables 5-D-13 through 5-D-16 are for the Removal alternative, with 50 percent infiltration.

Ammonia removal of 0 percent, 50 percent, and 85 percent was computed assuming site infiltration was reduced to 50 percent. Figure 5-D-24 shows a summary comparison of mass flux for ammonia removal using the mass flux over time from Alternative 1 (No Action), the 50 percent ammonia removal (with reduced infiltration over the area shown in Figure 5-D-12) from Alternative 3 (Removal), and the 85 percent ammonia removal (again based on the Alternative 3, 50 percent infiltration case). The scenario developed here for 85 percent ammonia removal was the basis for the remedy evaluation and cost estimation in Section 5 of this FS for Alternative 2 (Containment). Table 5-D-17 shows the calculated surface water quality for the peak ammonia loading to the lake east of the site for these three cases.

Several conclusions can be drawn from the mass flux analysis of the alternatives. Alternatives 2 and 3 provide very similar reductions in mass flux compared to No Action. The mass flux reductions provided by Alternatives 2 and 3 are long term, remaining significantly below the No Action flux throughout the modeled duration.

A comparison of surface water standards and the calculated surface water quality for the No Action alternative is shown in Table 5-D-18 (all calculated values are rounded to two significant figures). No exceedances are shown for arsenic. Phenols are highly biodegradable and are significantly attenuated, and so are subject to significant concentration (and mass flux) reductions during migration. These effects may be very significant during travel after passing the shoreline. As a result of these attenuation and degradation effects, the exceedances of Open Waters standards shown for "Lake Michigan East of the Site" are unlikely to be observed. The model predicts that ammonia would exceed Open Waters standards for "Lake Michigan East of the Site" under low mixing

conditions, but not average mixing conditions. The calculated concentration of 64 µg/L is more than an order of magnitude below the aquatic life criteria value (chronic) of 1,490 µg/L for ammonia.

A comparison of the surface water standards and the calculated surface water quality for the Containment alternative is shown in Table 5-D-19 (all calculated values are rounded to two significant figures). No exceedances are shown for arsenic. Phenols are highly degradable, so exceedances of standards would be unlikely as a result of groundwater discharges, as explained above for No Action. The model predicts an ammonia concentration of 21 µg/L (assuming 85 percent removal in the cells) under low mixing conditions in Lake Michigan east of the site. This concentration is practically the same as the standard, 20 µg/L.

A comparison of the surface water standards and the calculated surface water quality for the Removal alternative is shown in Table 5-D-20 (all calculated values are rounded to two significant figures). Calculated values are shown as a range to reflect the range of infiltration reduction effectiveness modeled for the cap, and to reflect the range of ammonia treatment effectiveness described in Appendix 5-B. No exceedances of surface water standards are shown for arsenic. Phenols are highly degradable, so exceedances of standards would be unlikely as a result of groundwater discharges, as explained above for No Action. The model predicts no ammonia exceedances with the possible exception of the low mixing case for Lake Michigan east of the site. For ammonia mass removal from groundwater treatment cells of 50 percent, the model predicts a 37 µg/L surface water concentration. For 85 percent ammonia removal from the groundwater treatment cells, the calculated surface water ammonia concentration is 21 µg/L. This concentration is practically the same as the standard, 20 µg/L. It should be noted that the mass flux producing the potential exceedance is the highest mass flux projected, and lasts for only a few years immediately following remedy implementation. In view of the conservativeness of the mass flux estimation procedure, groundwater discharges are not expected to produce the minor exceedance of surface water standards calculated for ammonia after remedy.

This analysis concludes that the Alternative 3, Removal, and the Alternative 2, Containment remedies are capable of treating and managing groundwater to protect against surface water standards exceedances, even under low surface water mixing conditions.

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Table 5-D-1
No Action (100% Infiltration)
Waukegan Harbor Surface Water Model
Waukegan Manufactured Gas & Coke Plant Site

Waukegan Harbor			
Scenario	Case 1	Case 2	Case 3
	Average Flow	Low Flow	High Flow
Lake inflows to Harbor (m^3/day)	57,029	57,029	57,029
Reciprocal flows (m^3/day)	184,312	60,479	888,871
Harbor outflow (m^3/day)	241,342	117,509	945,900
Mass Discharge (kg/day)	Concentration in mixing zone (ug/l)		
Ammonia	25.57	106	218	27.0
Phenols	4.26	17.7	36.3	4.50
Arsenic	0.19	0.787	1.62	0.201

Table 5-D-2
No Action (100% Infiltration)
Lake Michigan Surface Water Model
Longshore Current Zone
Waukegan Manufactured Gas & Coke Plant Site

Lake Michigan				
Scenario		Case 1	Case 2	Case 3
		Average Flow	Low Flow	High Flow
Current velocity (m/s)		0.082	0.026	0.158
Lake segment inflows (m^3/day)		17,768,678	3,250,863	34,242,425
	Mass Discharge (kg/day)	Concentration in mixing zone (ug/l)		
Ammonia	50.91	2.87	15.66	1.49
Phenols	13.62	0.767	4.19	0.398
Arsenic	1.10	0.062	0.338	0.0321

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Table 5-D-3
No Action (100% Infiltration)
Lake Michigan Surface Water Model
Near Shore Mixing Zone
To Lake Michigan (JK)
Waukegan Manufactured Gas & Coke Plant Site

Lake Michigan				
Scenario		Case 1	Case 2	Case 3
		Average Flow	Low Flow	High Flow
Current velocity (m/s)		0.090	0.064	0.488
Lake segment inflows (m^3/day)		1,417,322	356,358	2,715,112
	Mass Discharge (kg/day)	Concentration in mixing zone (ug/l)		
Ammonia	22.88	16.14	64.2	8.43
Phenols	8.32	5.870	23.35	3.064
Arsenic	0.62	0.437	1.740	0.228

Table 5-D-4
No Action (100% Infiltration)
Lake Michigan Surface Water Model
Near Shore Mixing Zone
To Breakwater Area (HJ)
Waukegan Manufactured Gas & Coke Plant Site

Lake Michigan				
Scenario		Case 1	Case 2	Case 3
		Average Flow	Low Flow	High Flow
Current velocity (m/s)		0.064	0.013	0.27
Lake segment inflows (m^3/day)		763,811	156,125	3,242,592
	Mass Discharge (kg/day)	Concentration in mixing zone (ug/l)		
Ammonia	13.7	17.94	87.75	4.23
Phenols	1.97	2.579	12.62	0.608
Arsenic	0.44	0.576	2.818	0.136

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Table 5-D-5
Containment (50% Infiltration)
Waukegan Harbor Surface Water Model
Waukegan Manufactured Gas & Coke Plant Site

Waukegan Harbor			
Scenario	Case 1	Case 2	Case 3
	Average Flow	Low Flow	High Flow
Lake inflows to Harbor (m^3/day)	57,029	57,029	57,029
Reciprocal flows (m^3/day)	184,312	60,479	888,871
Harbor outflow (m^3/day)	241,342	117,509	945,900
Mass Discharge (kg/day)	Concentration in mixing zone (ug/l)		
Ammonia	14.13	58.5	120	14.9
Phenols	2.42	10.0	20.6	2.56
Arsenic	0.10	0.41	0.85	0.11

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Table 5-D-6
Containment (50% Infiltration)
Lake Michigan Surface Water Model
Longshore Current Zone
Waukegan Manufactured Gas & Coke Plant Site

Lake Michigan				
Scenario		Case 1	Case 2	Case 3
		Average Flow	Low Flow	High Flow
Current velocity (m/s)		0.082	0.026	0.158
Lake segment inflows (m^3/day)		17,768,678	3,250,863	34,242,425
	Mass Discharge (kg/day)	Concentration in mixing zone (ug/l)		
Ammonia	31.02	1.75	9.54	0.91
Phenols	5.93	0.334	1.82	0.173
Arsenic	0.30	0.017	0.092	0.0088

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Table 5-D-7
Containment (50% Infiltration)
Lake Michigan Surface Water Model
Near Shore Mixing Zone
To Lake Michigan (JK)
Waukegan Manufactured Gas & Coke Plant Site

Lake Michigan				
Scenario		Case 1	Case 2	Case 3
		Average Flow	Low Flow	High Flow
Current velocity (m/s)		0.090	0.064	0.488
Lake segment inflows (m^3/day)		1,417,322	356,358	2,715,112
	Mass Discharge (kg/day)	Concentration in mixing zone (ug/l)		
Ammonia	12.53	8.84	35.2	4.61
Phenols	3.90	2.752	10.94	1.436
Arsenic	0.13	0.092	0.365	0.048

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Table 5-D-8
Containment (50% Infiltration)
Lake Michigan Surface Water Model
Near Shore Mixing Zone
To Breakwater Area (HJ)
Waukegan Manufactured Gas & Coke Plant Site

Lake Michigan				
Scenario		Case 1	Case 2	Case 3
		Average Flow	Low Flow	High Flow
Current velocity (m/s)		0.064	0.013	0.27
Lake segment inflows (m^3/day)		763,811	156,125	3,242,592
	Mass Discharge (kg/day)	Concentration in mixing zone (ug/l)		
Ammonia	10.18	13.33	65.20	3.14
Phenols	1.07	1.401	6.85	0.330
Arsenic	0.11	0.144	0.705	0.034

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Table 5-D-9
Removal (0% Infiltration)
Waukegan Harbor Surface Water Model
Waukegan Manufactured Gas & Coke Plant Site

Waukegan Harbor				
Scenario		Case 1	Case 2	Case 3
		Average Flow	Low Flow	High Flow
Lake Inflows to Harbor (m^3/day)		57,029	57,029	57,029
Reciprocal flows (m^3/day)		184,312	60,479	888,871
Harbor outflow (m^3/day)		241,342	117,509	945,900
	Mass Discharge (kg/day)	Concentration in mixing zone (ug/l)		
Ammonia	14.07	58.3	120	14.9
Phenols	2.41	10.0	20.5	2.5
Arsenic	0.10	0.41	0.85	0.11

((

Table 5-D-10
Removal (0% Infiltration)
Lake Michigan Surface Water Model
Longshore Current Zone
Waukegan Manufactured Gas & Coke Plant Site

Lake Michigan				
Scenario		Case 1	Case 2	Case 3
		Average Flow	Low Flow	High Flow
Current velocity (m/s)		0.082	0.026	0.158
Lake segment inflows (m^3/day)		17,768,678	3,250,863	34,242,425
	Mass Discharge (kg/day)	Concentration in mixing zone (ug/l)		
Ammonia	28.14	1.58	8.7	0.82
Phenols	5.15	0.290	1.58	0.150
Arsenic	0.29	0.016	0.089	0.0085

((

Table 5-D-11
Removal (0% Infiltration)
Lake Michigan Surface Water Model
Near Shore Mixing Zone
To Lake Michigan (JK)
Waukegan Manufactured Gas & Coke Plant Site

Lake Michigan				
Scenario		Case 1	Case 2	Case 3
		Average Flow	Low Flow	High Flow
Current velocity (m/s)		0.090	0.064	0.488
Lake segment inflows (m^3/day)		1,417,322	356,358	2,715,112
	Mass Discharge (kg/day)	Concentration in mixing zone (ug/l)		
Ammonia	13.06	9.21	36.6	4.81
Phenols	3.00	2.117	8.42	1.105
Arsenic	0.14	0.099	0.393	0.052

((

Table 5-D-12
Removal (0% Infiltration)
Lake Michigan Surface Water Model
Near Shore Mixing Zone
To Breakwater Area (HJ)
Waukegan Manufactured Gas & Coke Plant Site

Lake Michigan				
Scenario		Case 1	Case 2	Case 3
		Average Flow	Low Flow	High Flow
Current velocity (m/s)		0.064	0.013	0.27
Lake segment inflows (m^3/day)		763,811	156,125	3,242,592
	Mass Discharge (kg/day)	Concentration in mixing zone (ug/l)		
Ammonia	7.5	9.82	48.04	2.31
Phenols	0.57	0.746	3.65	0.176
Arsenic	0.08	0.105	0.512	0.025

((

Table 5-D-13
Removal (50% Infiltration)
Waukegan Harbor Surface Water Model
Waukegan Manufactured Gas & Coke Plant Site

Waukegan Harbor				
Scenario		Case 1	Case 2	Case 3
		Average Flow	Low Flow	High Flow
Lake inflows to Harbor (m^3/day)		57,029	57,029	57,029
Reciprocal flows (m^3/day)		184,312	60,479	888,871
Harbor outflow (m^3/day)		241,342	117,509	945,900
	Mass Discharge (kg/day)	Concentration in mixing zone (ug/l)		
Ammonia	20.92	87	178	22
Phenols	3.28	14	28	3.5
Arsenic	0.14	0.58	1.19	0.15

((

Table 5-D-14
Removal (50% Infiltration)
Lake Michigan Surface Water Model
Longshore Current Zone
Waukegan Manufactured Gas & Coke Plant Site

Lake Michigan				
Scenario		Case 1	Case 2	Case 3
		Average Flow	Low Flow	High Flow
Current velocity (m/s)		0.082	0.026	0.158
Lake segment inflows (m^3/day)		17,768,678	3,250,863	34,242,425
	Mass Discharge (kg/day)	Concentration in mixing zone (ug/l)		
Ammonia	35.89	2.02	11.0	1.05
Phenols	7.49	0.422	2.30	0.219
Arsenic	0.36	0.020	0.111	0.0105

06/30/98
10:42

Table 5-D-15
Removal (50% Infiltration)
Lake Michigan Surface Water Model
Near Shore Mixing Zone
To Lake Michigan (JK)
Waukegan Manufactured Gas & Coke Plant Site

Lake Michigan				
Scenario		Case 1	Case 2	Case 3
		Average Flow	Low Flow	High Flow
Current velocity (m/s)		0.090	0.064	0.488
Lake segment inflows (m^3/day)		1,417,322	356,358	2,715,112
	Mass Discharge (kg/day)	Concentration in mixing zone (ug/l)		
Ammonia	13.27	9.36	37.2	4.89
Phenols	3.88	2.738	10.89	1.429
Arsenic	0.14	0.099	0.393	0.052

((

Table 5-D-16
Removal (50% Infiltration)
Lake Michigan Surface Water Model
Near Shore Mixing Zone
To Breakwater Area (HJ)
Waukegan Manufactured Gas & Coke Plant Site

Lake Michigan				
Scenario		Case 1	Case 2	Case 3
		Average Flow	Low Flow	High Flow
Current velocity (m/s)		0.064	0.013	0.27
Lake segment inflows (m^3/day)		763,811	156,125	3,242,592
	Mass Discharge (kg/day)	Concentration in mixing zone (ug/l)		
Ammonia	11.05	14.47	70.78	3.41
Phenols	1.18	1.545	7.56	0.364
Arsenic	0.12	0.157	0.769	0.037

Table 5-D-17
Lake Michigan Surface Water Model
Near Shore Mixing Zone
To Lake Michigan (JK)
Waukegan Manufactured Gas & Coke Plant Site

Lake Michigan				
Scenario		Case 1	Case 2	Case 3
		Average Flow	Low Flow	High Flow
Current velocity (m/s)		0.090	0.064	0.488
Lake segment inflows (m^3/day)		1,417,322	356,358	2,715,112
	Mass Discharge (kg/day)	Concentration in mixing zone (ug/l)		
0% Ammonia Removal in Groundwater Treatment Area	22.88	16.1	64.2	8.43
50% Ammonia Removal in Groundwater Treatment Area	13.27	9.36	37.2	4.89
85% Ammonia Removal in Groundwater Treatment Area	7.61	5.37	21.4	2.80

Table 5-D-18

Alternative 1, No Action
Computed Surface Water Quality (Assuming Maximum Projected Groundwater Loading)

	Mixing Ratio	Surface Water Concentration[1]		
		Arsenic (µg/L)	Phenols (µg/L)	Ammonia (µg/L)
Lake Michigan Basin Water Quality Standards		148 chronic 340 acute	100	15,000[2]
Waukegan Harbor, Calculated Water Quality	High (6,200:1)	0.20	4.5	30
	Average (1,600:1)	0.79	18	110
	Low (800:1)	1.6	36	220
Breakwater Area, Calculated Water Quality	High (32,000:1)	0.14	0.61	4.2
	Average (7,600:1)	0.58	2.6	18
	Low (1,600:1)	2.8	13	88
Lake Michigan Open Waters Water Quality Standards		50	1	20
Lake Michigan East of Site, Calculated Water Quality	High (22,000:1)	0.23	3.1	8.4
	Average (12,000:1)	0.44	5.9	16
	Low (2,900:1)	1.7	23	64
Longshore Current Zone, Calculated Water Quality	High (90,000:1)	0.032	0.40	1.5
	Average (50,000:1)	0.062	0.77	2.9
	Low (9,000:1)	0.34	4.2	16
National Ambient Water Quality Criteria for the Protection of Aquatic Life	—	190 chronic	117 chronic	1,490 chronic
		360 acute	2,010 acute	2,600 acute

[1] The computed surface water concentrations are highly conservative because, in addition to using the peak groundwater mass flux, they do not account for natural attenuation mechanisms that remove mass, such as anaerobic biodegradation, aerobic biodegradation, adsorption, and chemical changes.

[2] In addition, un-ionized ammonia nitrogen must meet the following acute and chronic standards: April through October, acute 330 µg/L, chronic 57 µg/L; November through March, acute 140 µg/L, chronic 25 µg/L.

Table 5-D-19

Alternative 2, Containment
Computed Surface Water Quality (Assuming Maximum Projected Groundwater Loading)

	Mixing Ratio	Surface Water Concentration[1]		
		Arsenic (µg/L)	Phenols (µg/L)	Ammonia (µg/L)
Lake Michigan Basin Water Quality Standards		148 chronic 340 acute	100	15,000[2]
Waukegan Harbor, Calculated Water Quality	High (6,200:1)	0.11	2.6	15
	Average (1,600:1)	0.41	10	59
	Low (800:1)	0.85	21	120
Breakwater Area, Calculated Water Quality	High (32,000:1)	0.034	0.33	3.1
	Average (7,600:1)	0.14	1.4	13
	Low (1,600:1)	0.71	6.9	65
Lake Michigan Open Waters Water Quality Standards		50	1	20
Lake Michigan East of Site, Calculated Water Quality	High (22,000:1)	0.048	1.4	2.8
	Average (12,000:1)	0.092	2.8	5.4
	Low (2,900:1)	0.37	11	21
Longshore Current Zone, Calculated Water Quality	High (90,000:1)	0.0088	0.17	0.91
	Average (50,000:1)	0.017	0.33	1.8
	Low (9,000:1)	0.092	1.8	9.5
National Ambient Water Quality Criteria for the Protection of Aquatic Life	—	190 chronic	117 chronic	1,490 chronic
		360 acute	2,010 acute	2,600 acute

[1] The computed surface water concentrations are highly conservative because, in addition to using the peak groundwater mass flux, they do not account for natural attenuation mechanisms that remove mass, such as anaerobic biodegradation, aerobic biodegradation, adsorption, and chemical changes.

[2] In addition, un-ionized ammonia nitrogen must meet the following acute and chronic standards: April through October, acute 330 µg/L, chronic 57 µg/L; November through March, acute 140 µg/L, chronic 25 µg/L.

Table 5-D-20

Alternative 3, Removal
Computed Surface Water Quality (Assuming Maximum Projected Groundwater Loading)

	Mixing Ratio	Surface Water Concentration[1]		
		Arsenic (µg/L)	Phenols (µg/L)	Ammonia (µg/L)
Lake Michigan Basin Water Quality Standards		**148 chronic 340 acute**	**100**	**15,000[2]**
Waukegan Harbor, Calculated Water Quality	High (6,200:1)	0.11-0.15	2.5-3.5	15-22
	Average (1,600:1)	0.41-0.58	10-14	58-87
	Low (800:1)	0.85-1.2	21-28	120-180
Breakwater Area, Calculated Water Quality	High (32,000:1)	0.025-0.037	0.18-0.36	2.3-3.4
	Average (7,600:1)	0.11-0.16	0.75-1.5	9.8-14
	Low (1,600:1)	0.51-0.77	3.7-7.6	48-71
Lake Michigan Open Waters Water Quality Standards		**50**	**1**	**20**
Lake Michigan East of Site, Calculated Water Quality	High (22,000:1)	0.052-0.052	1.1-1.4	2.8-4.9
	Average (12,000:1)	0.099-0.099	2.1-2.7	5.4-9.4
	Low (2,900:1)	0.39-0.39	8.4-11	21-37
Longshore Current Zone, Calculated Water Quality	High (90,000:1)	0.0085-0.011	0.15-0.22	0.82-1.1
	Average (50,000:1)	0.016-0.020	0.29-0.42	1.6-2.0
	Low (9,000:1)	0.089-0.11	1.6-2.3	8.7-11
National Ambient Water Quality Criteria for the Protection of Aquatic Life	—	**190 chronic**	**117 chronic**	**1,490 chronic**
		360 acute	**2,010 acute**	**2,600 acute**

[1]   The computed surface water concentrations are highly conservative because, in addition to using the peak groundwater mass flux, they do not account for natural attenuation mechanisms that remove mass, such as anaerobic biodegradation, aerobic biodegradation, adsorption, and chemical changes.

[2]   In addition, un-ionized ammonia nitrogen must meet the following acute and chronic standards: April through October, acute 330 µg/L, chronic 57 µg/L; November through March, acute 140 µg/L, chronic 25 µg/L.

LAKE MICHIGAN

🅝

SITE

CITY OF WAUKEGAN
WATERWORKS

WAUKEGAN
HARBOR

NORTH
HARBOR
WALL

BREAKWATER PIER

HARBOR PIER

MARINA BREAKWATER

**LAKE
MICHIGAN**

Open Waters	
Ammonia...	0.020 mg/L
Arsenic......	0.050 mg/L
Phenols.....	0.001 mg/L

Harbor and Breakwater Areas	
Ammonia...	15 mg/L (See Note)
Arsenic......	0.148 mg/L
Phenols.....	0.100 mg/L

NOTE: Ammonia standards: maximum total
ammonia as N is 15 mg/L. In addition,
the following maximums apply to
un-ionized ammonia.

Un-ionized Ammonia (mg/L)

	Acute	Chronic
April - October	0.330	0.057
November - March	140	0.025

Figure 5-D-1

LAKE MICHIGAN SURFACE WATER QUALITY CRITERIA
Waukegan Manufactured Gas & Coke Plant Site

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LEGEND

Breakwater Discharge
Harbor Discharge
Lake Discharge

Lake Michigan

Waukegan Harbor

Breakwater Area
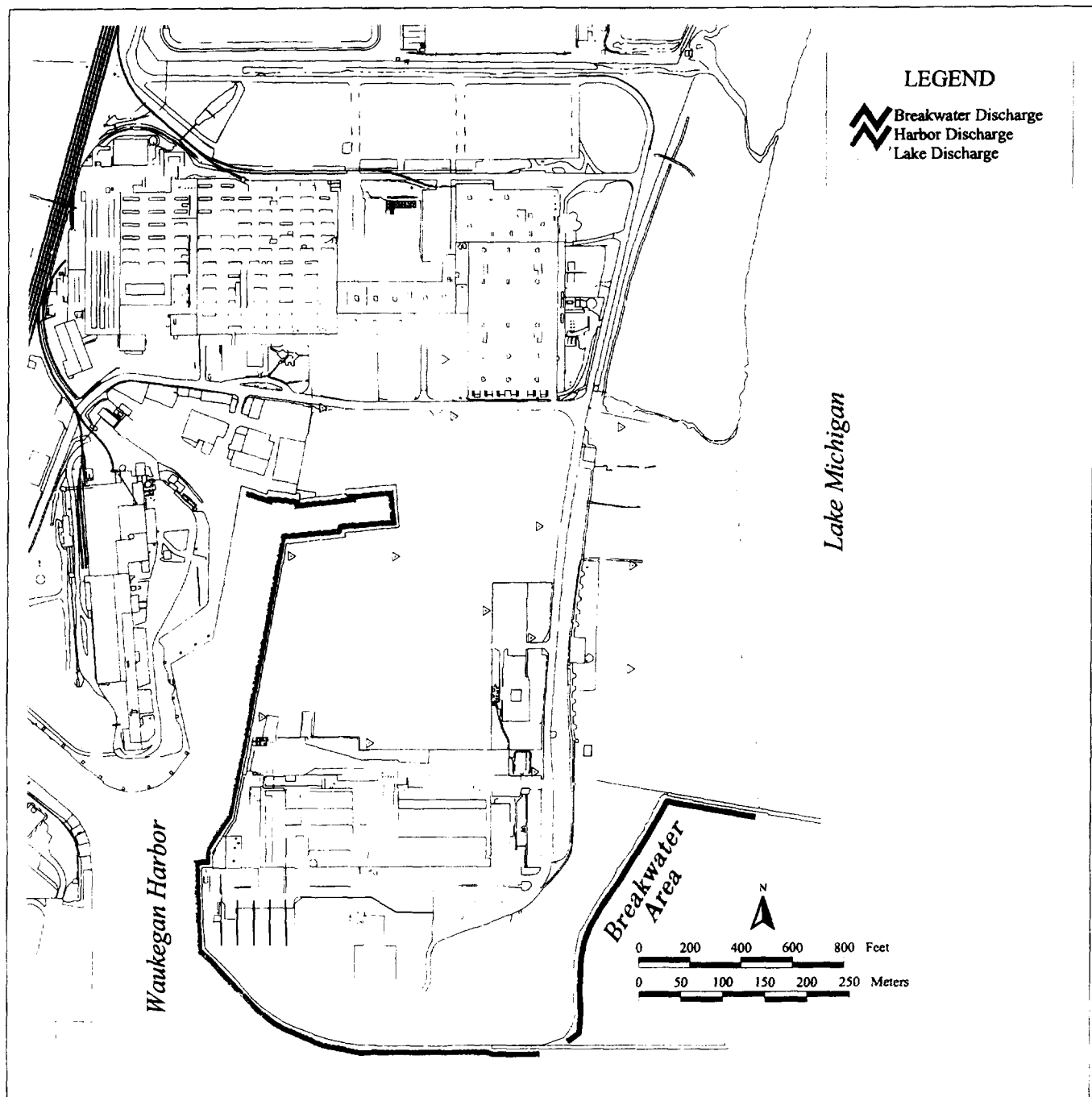
Figure 5-D-2

GROUNDWATER DISCHARGES AREAS
Waukegan Manufactured Gas & Coke Plant Site

LEGEND

0 mg/L

5 mg/L

10 mg/L

15 mg/L

20 mg/L

25 mg/L

30 mg/L

35 mg/L

40 mg/L

45 mg/L

50 mg/L

55 mg/L

60 mg/L

Lake Michigan

Waukegan Harbor

Breakwater Area

N

| 0 | 200 | 400 | 600 | 800 | Feet |

| 0 | 50 | 100 | 150 | 200 | 250 | Meters |
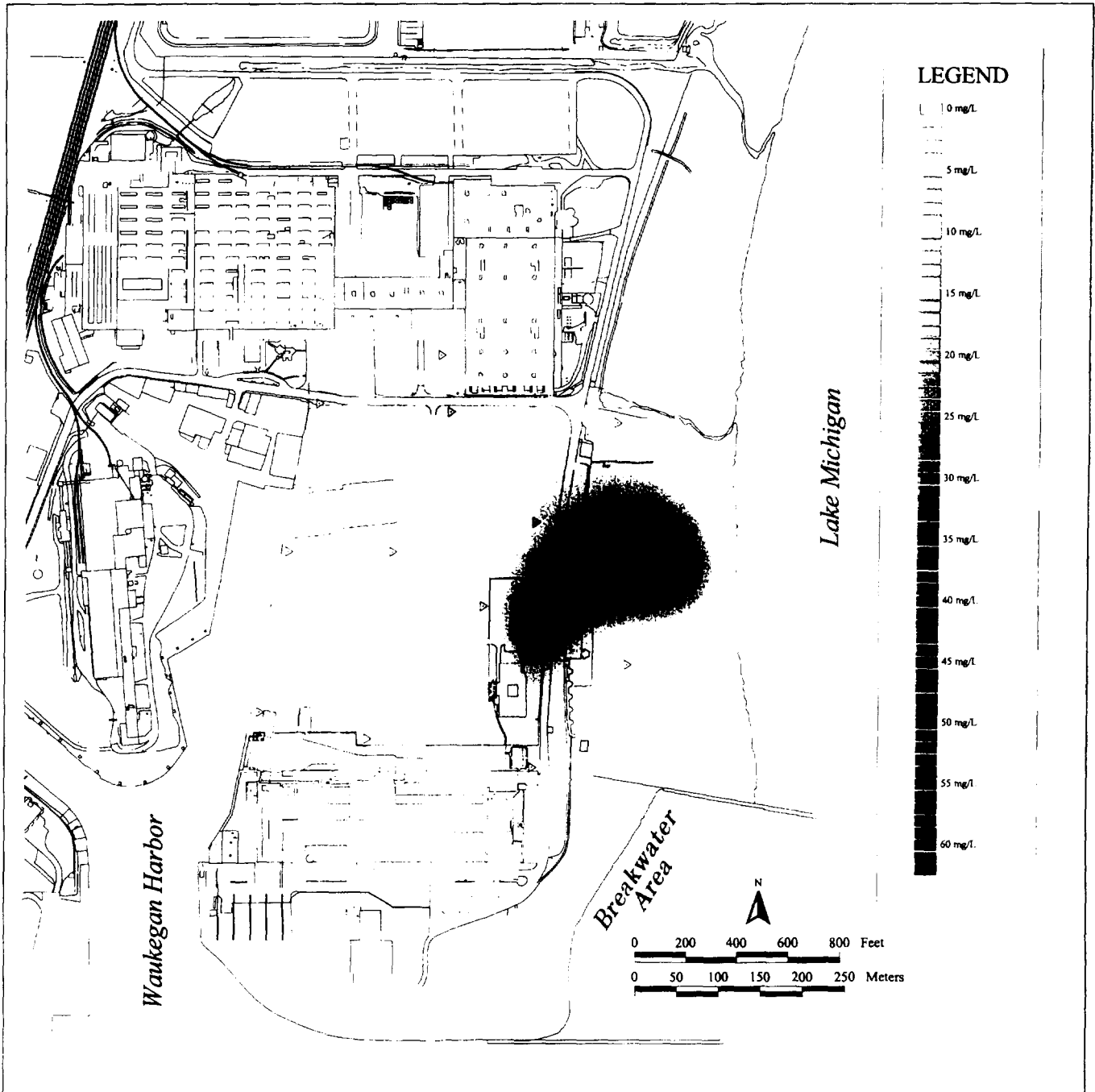
Figure 5-D-3

INITIAL PRE-REMOVAL CONCENTRATIONS
OF ARSENIC IN THE DEEP PORTION
OF THE SAND AQUIFER
Waukegan Manufactured Gas & Coke Plant Site
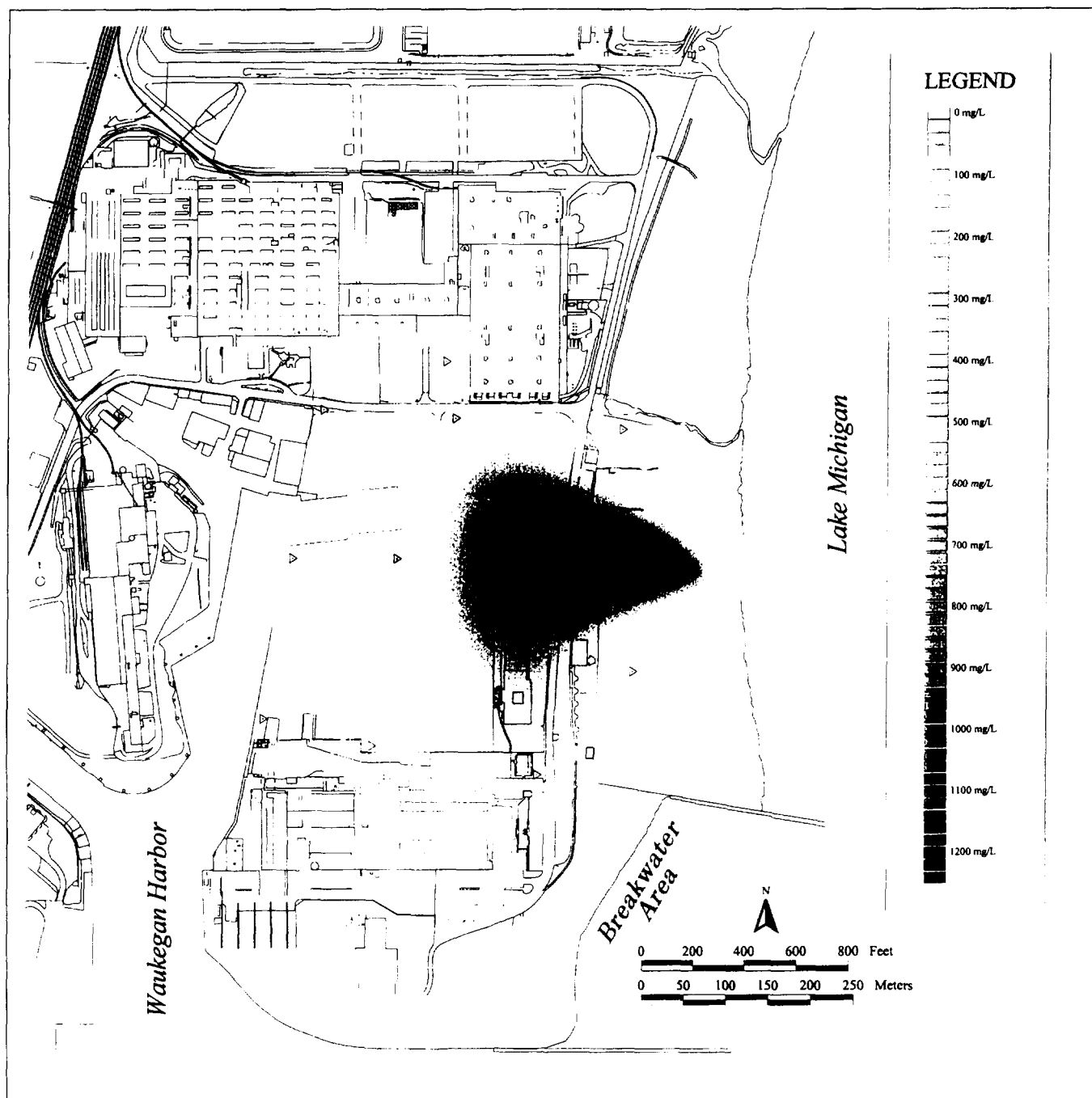
Figure 5-D-4

INITIAL PRE-REMOVAL CONCENTRATIONS
OF PHENOLS IN THE DEEP PORTION
OF THE SAND AQUIFER
Waukegan Manufactured Gas & Coke Plant Site

LEGEND

0 mg/L
200 mg/L
400 mg/L
600 mg/L
800 mg/L
1000 mg/l
1200 mg/l
1400 mg/L
1600 mg/l
1800 mg/L
2000 mg/l
2200 mg/l
2400 mg/L

Lake Michigan

Waukegan Harbor

Breakwater Area

0   200   400   600   800   Feet

0   50   100   150   200   250   Meters
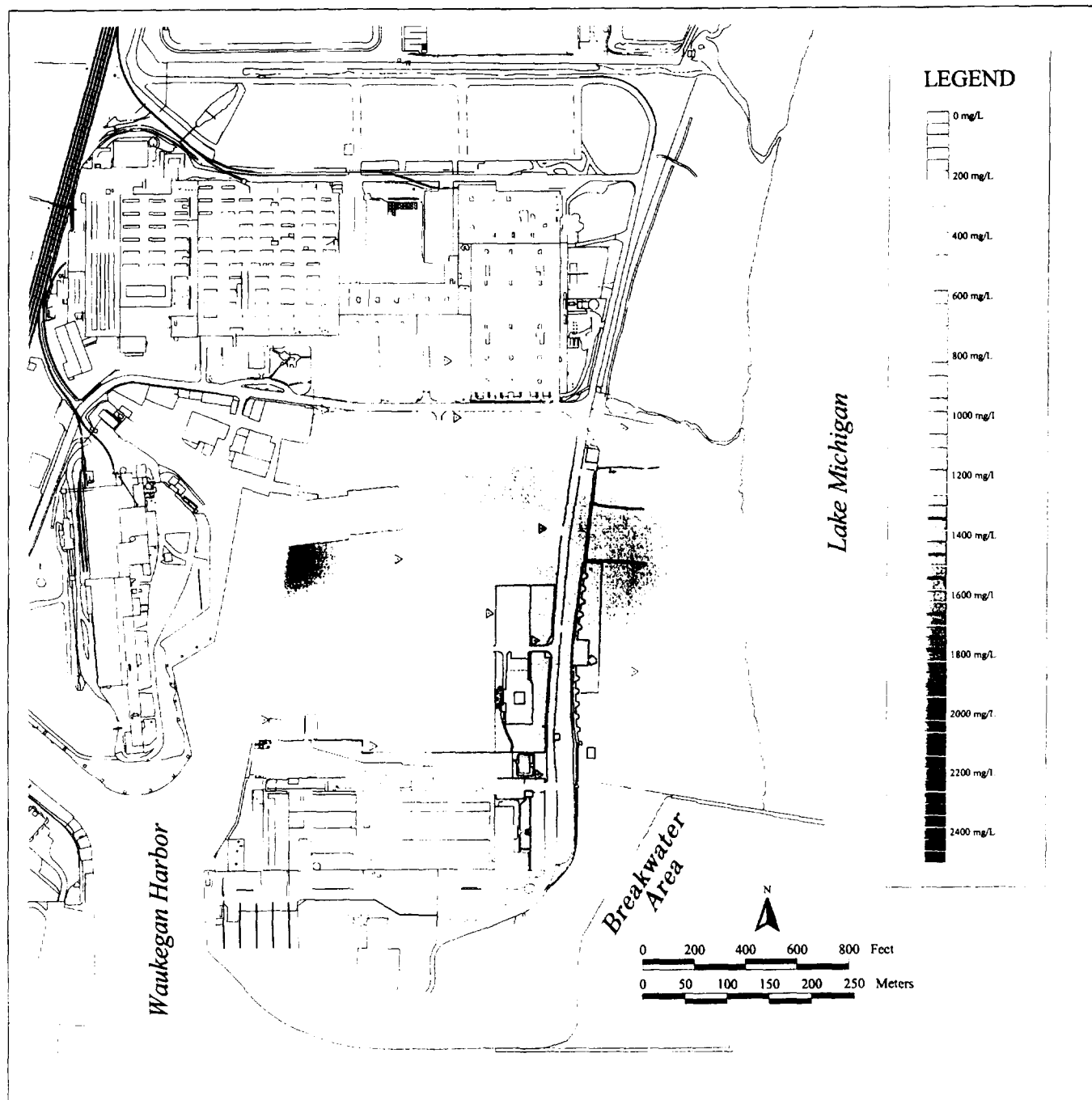
Figure 5-D-5

INITIAL PRE-REMOVAL CONCENTRATIONS
OF AMMONIA IN THE DEEP PORTION
OF THE SAND AQUIFER
Waukegan Manufactured Gas & Coke Plant Site

LEGEND

0 mg/L
5 mg/L
10 mg/L
15 mg/L
20 mg/L
25 mg/L
30 mg/L
35 mg/L
40 mg/L
45 mg/L
50 mg/L
55 mg/L
60 mg/L

Lake Michigan

Waukegan Harbor

Breakwater Area

N

| 0 | 200 | 400 | 600 | 800 | Feet |
| 0 | 50 | 100 | 150 | 200 | 250 | Meters |
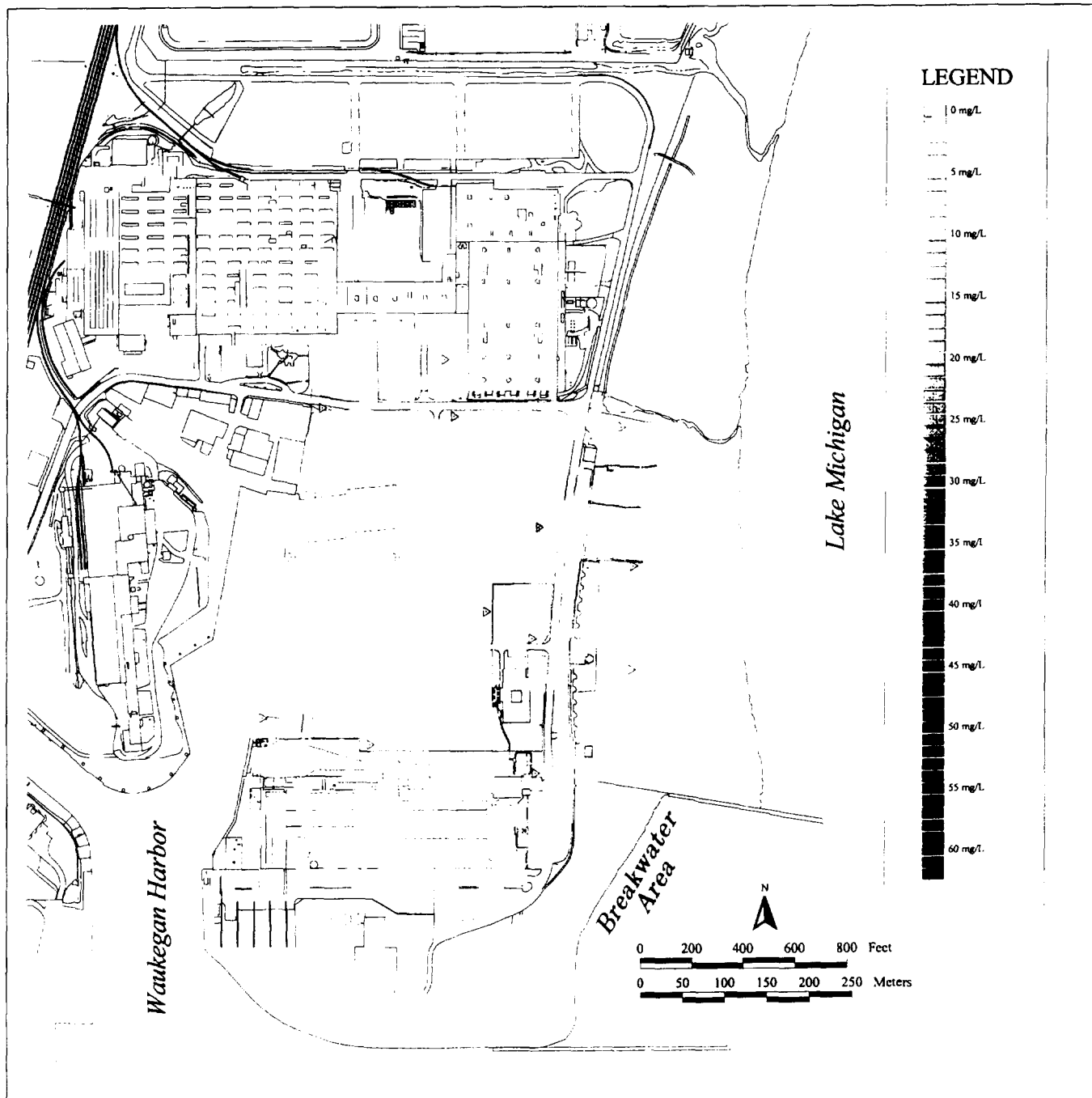
Figure 5-D-6

INITIAL POST-REMOVAL CONCENTRATIONS
OF ARSENIC IN THE DEEP PORTION
OF THE SAND AQUIFER
Waukegan Manufactured Gas & Coke Plant Site

LEGEND

0 mg/L
100 mg/L
200 mg/L
300 mg/L
400 mg/L
500 mg/L
600 mg/L
700 mg/L
800 mg/L
900 mg/L
1000 mg/L
1100 mg/L
1200 mg/L

Lake Michigan

Waukegan Harbor

Breakwater Area

0   200   400   600   800   Feet
0   50   100   150   200   250   Meters
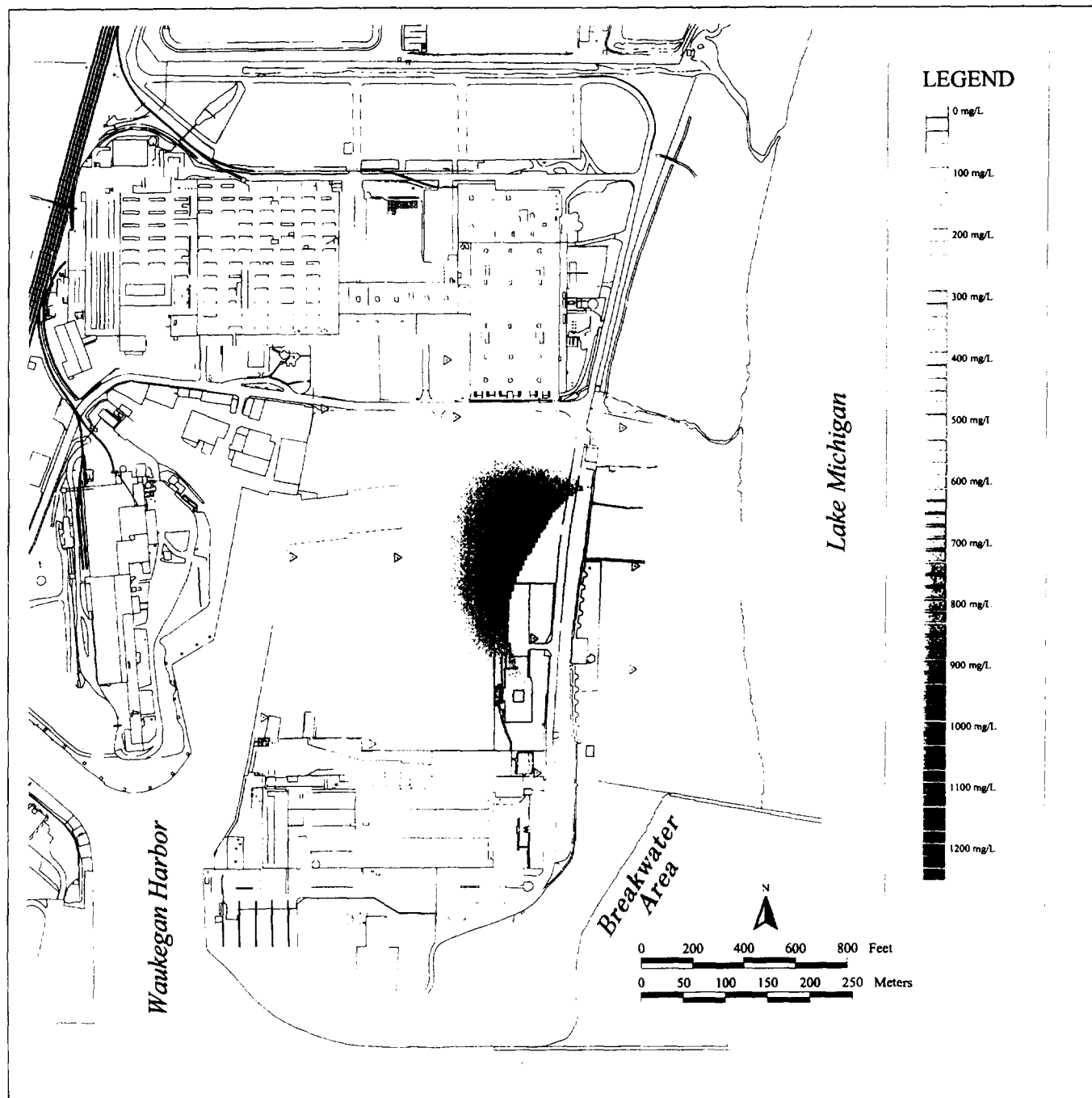
Figure 5-D-7

INITIAL POST-REMOVAL CONCENTRATIONS
OF PHENOLS IN THE DEEP PORTION
OF THE SAND AQUIFER
Waukegan Manufactured Gas & Coke Plant Site

LEGEND

	0 mg/L
	200 mg/L
	400 mg/L
	600 mg/L
	800 mg/L
	1000 mg/L
	1200 mg/L
	1400 mg/L
	1600 mg/L
	1800 mg/L
	2000 mg/L
	2200 mg/L
	2400 mg/L

Lake Michigan

Waukegan Harbor

Breakwater Area

N

| 0 | 200 | 400 | 600 | 800 Feet |
| 0 | 50 | 100 | 150 | 200 | 250 Meters |
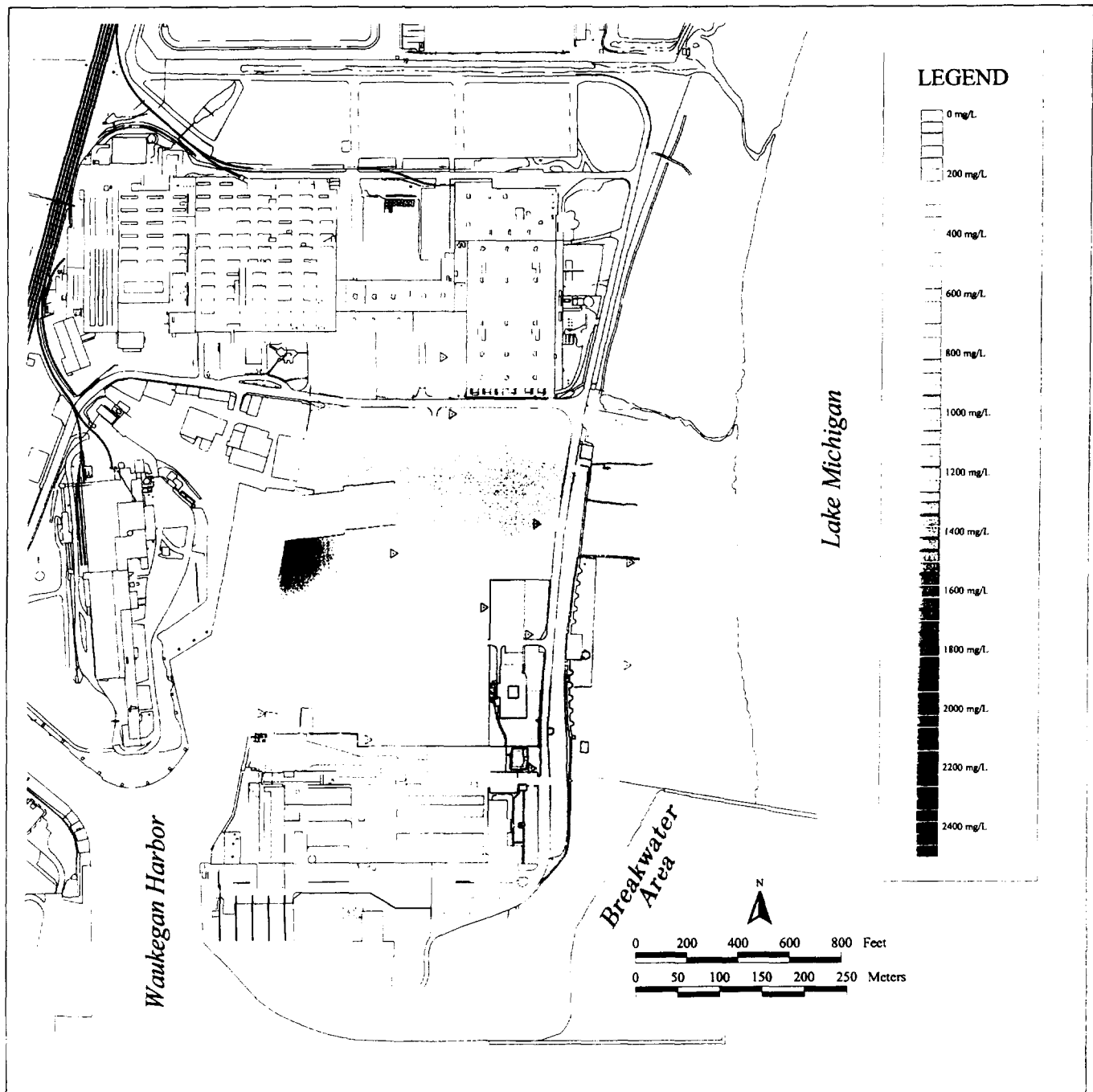
Figure 5-D-8

INITIAL POST-REMOVAL CONCENTRATIONS
OF AMMONIA IN THE DEEP PORTION
OF THE SAND AQUIFER
Waukegan Manufactured Gas & Coke Plant Site

Lake Michigan

Waukegan Harbor

582.75
582.50
582.25
582.00

582.50
582.25
582.00
581.75
581.50
581.25

0   600

Scale in Feet

LEGEND

——— Piezometric Head (ft,MSL)
.... Groundwater Pathway
━━━ Groundwater Divide
▷ Monitoring Well
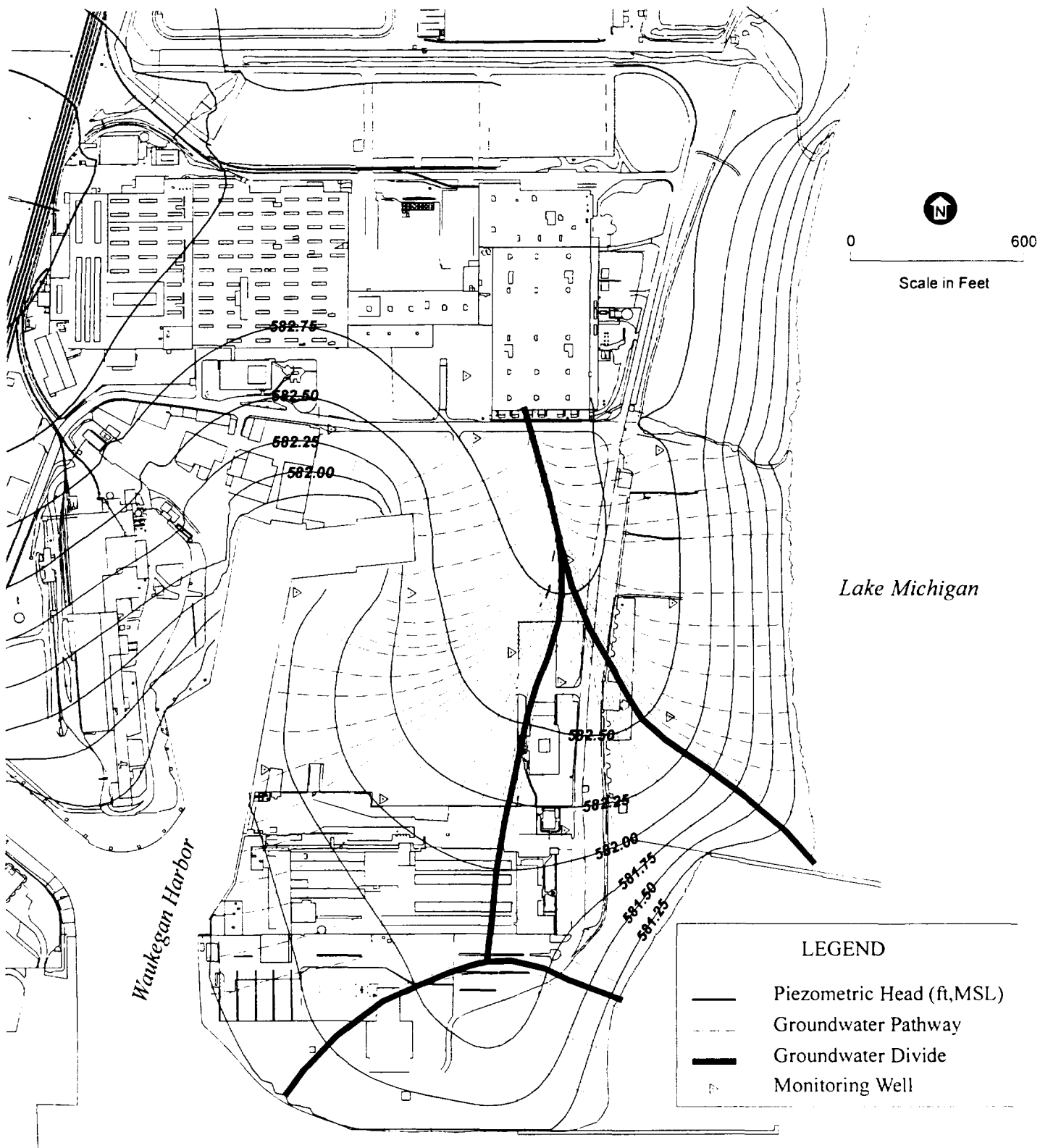
Figure 5-D-9

ALTERNATIVE 1 - NO ACTION
Waukegan Manufactured Gas & Coke Plant Site

Lake Michigan

Waukegan Harbor

0   600

Scale in Feet
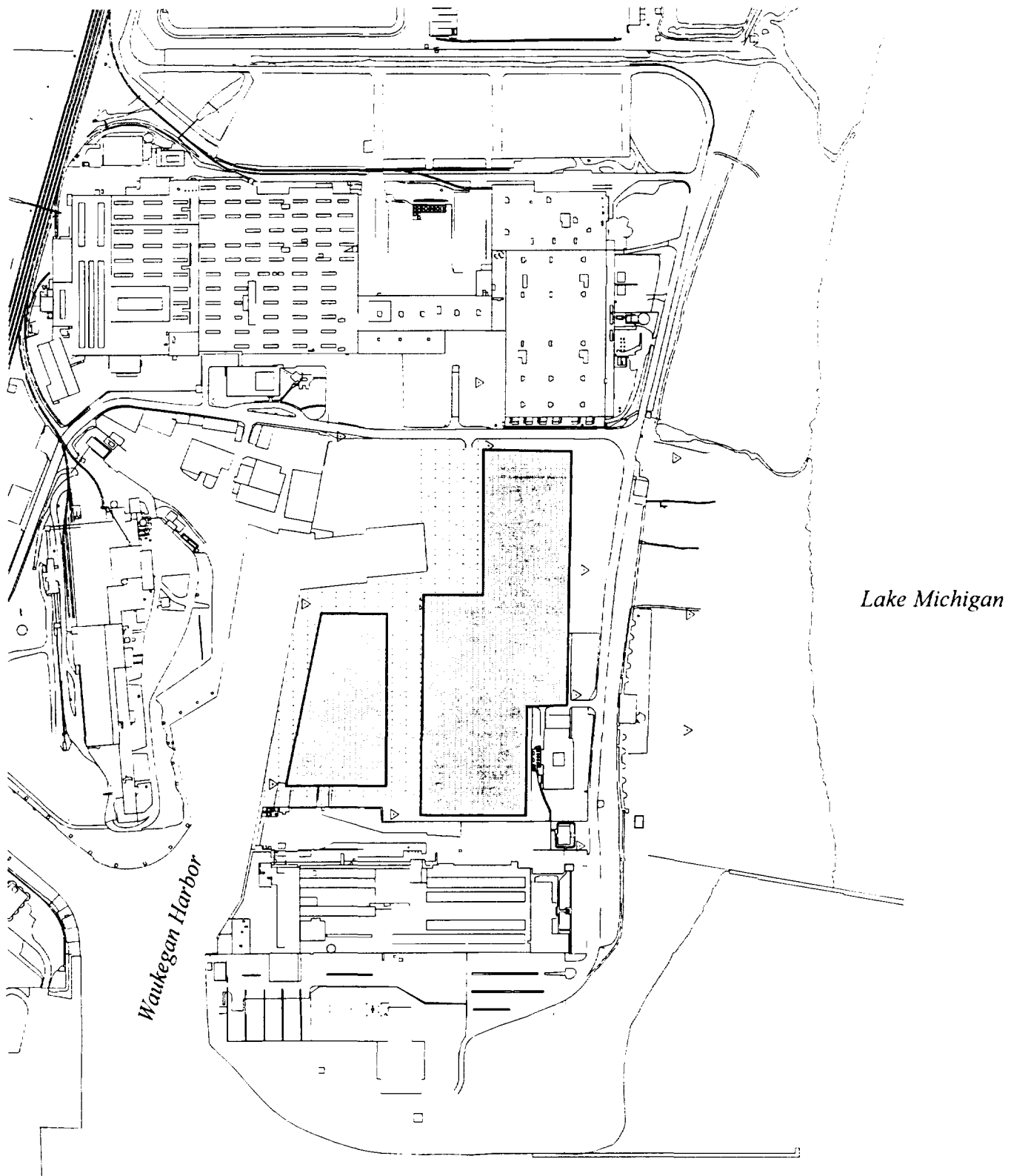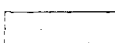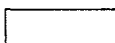
Infiltration Reduction Area (50% Infiltration)

Infiltration Reduction Area (0% Infiltration)

Figure 5-D10

MODELED INFILTRATION REDUCTION AREAS
ALTERNATIVE 2 (CONTAINMENT)
Waukegan Manufactured Gas & Coke Plant Site

582.75

582.50

582.25

582.00

582.50

Lake Michigan

582.25

582.00

581.75

581.50

581.25

Waukegan Harbor

0   60(

Scale in Feet

LEGEND

——— Piezometric Head (ft,MSL)
- - - - Groundwater Pathway
▬▬▬ Groundwater Divide
▷   Monitoring Well
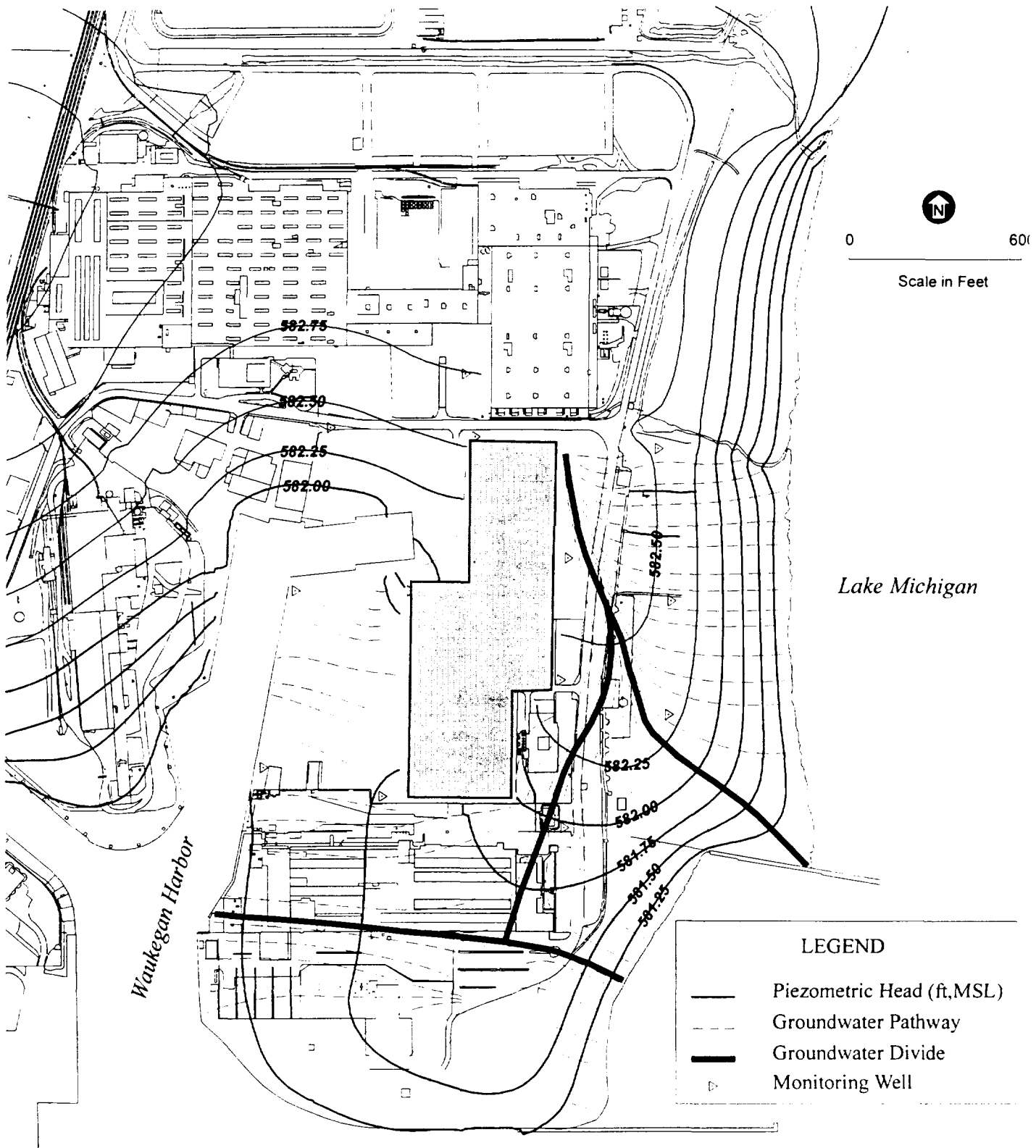
☐ Containment Unit

Figure 5-D-11

ALTERNATIVE 2 - CONTAINMENT
Waukegan Manufactured Gas & Coke Plant Site

P 1349003AL12CUNT CDR

Lake Michigan

Waukegan Harbor

0   600

Scale in Feet
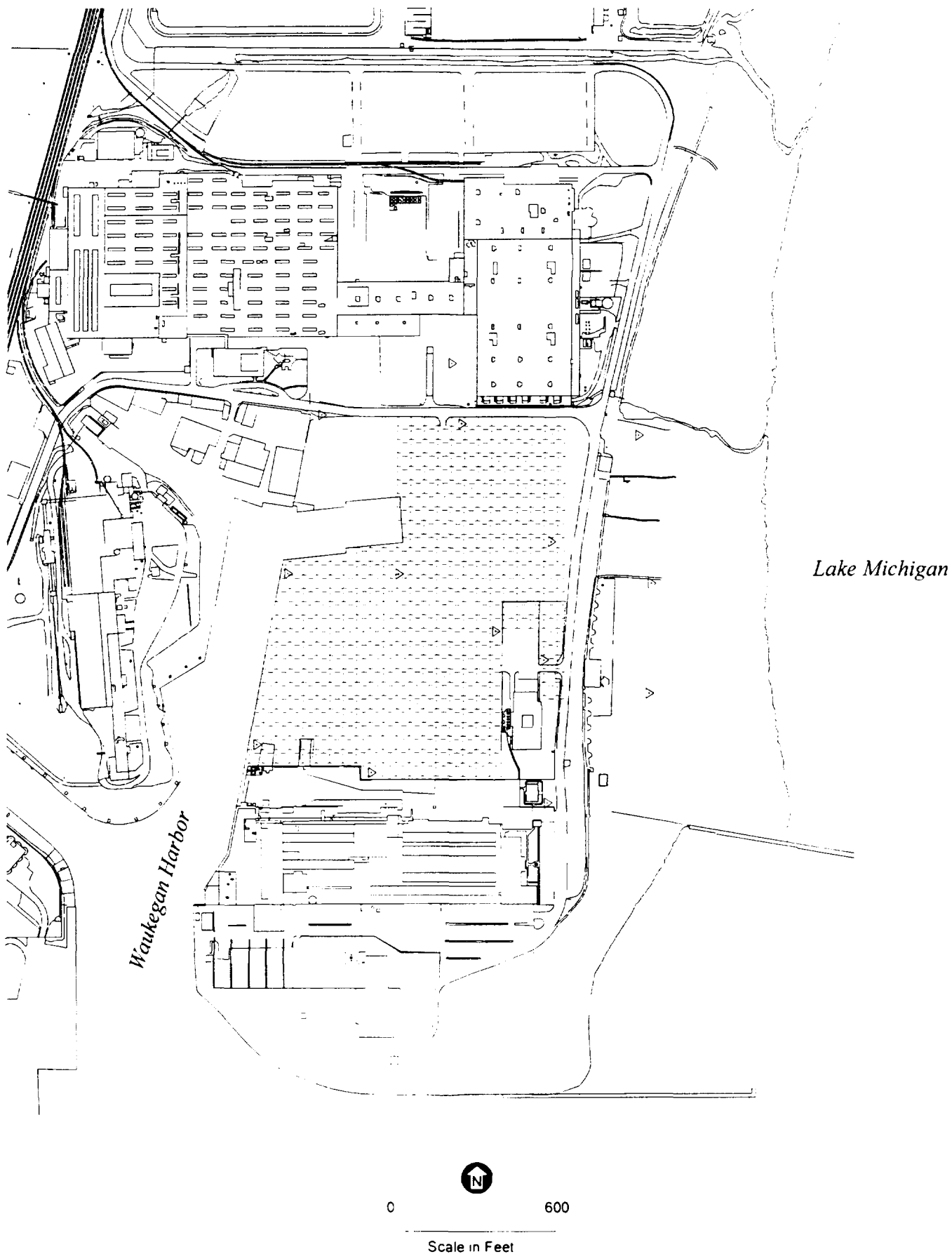
Figure 5-D-12

MODELED INFILTRATION REDUCTION AREAS
ALTERNATIVE 3 (REMOVAL)
Waukegan Manufactured Gas & Coke Plant Site

Infiltration Reduction Area
(0% and 50% Infiltartion)

P 1349003unf cdr

0   600
Scale in Feet

Lake Michigan

Waukegan Harbor

582.75

582.50

582.25

582.00

582.25

582.00

581.75

581.50

581.25

LEGEND

—————— Piezometric Head (ft.MSL)
············· Groundwater Pathway
▬▬▬▬▬ Groundwater Divide
▷ Monitoring Well
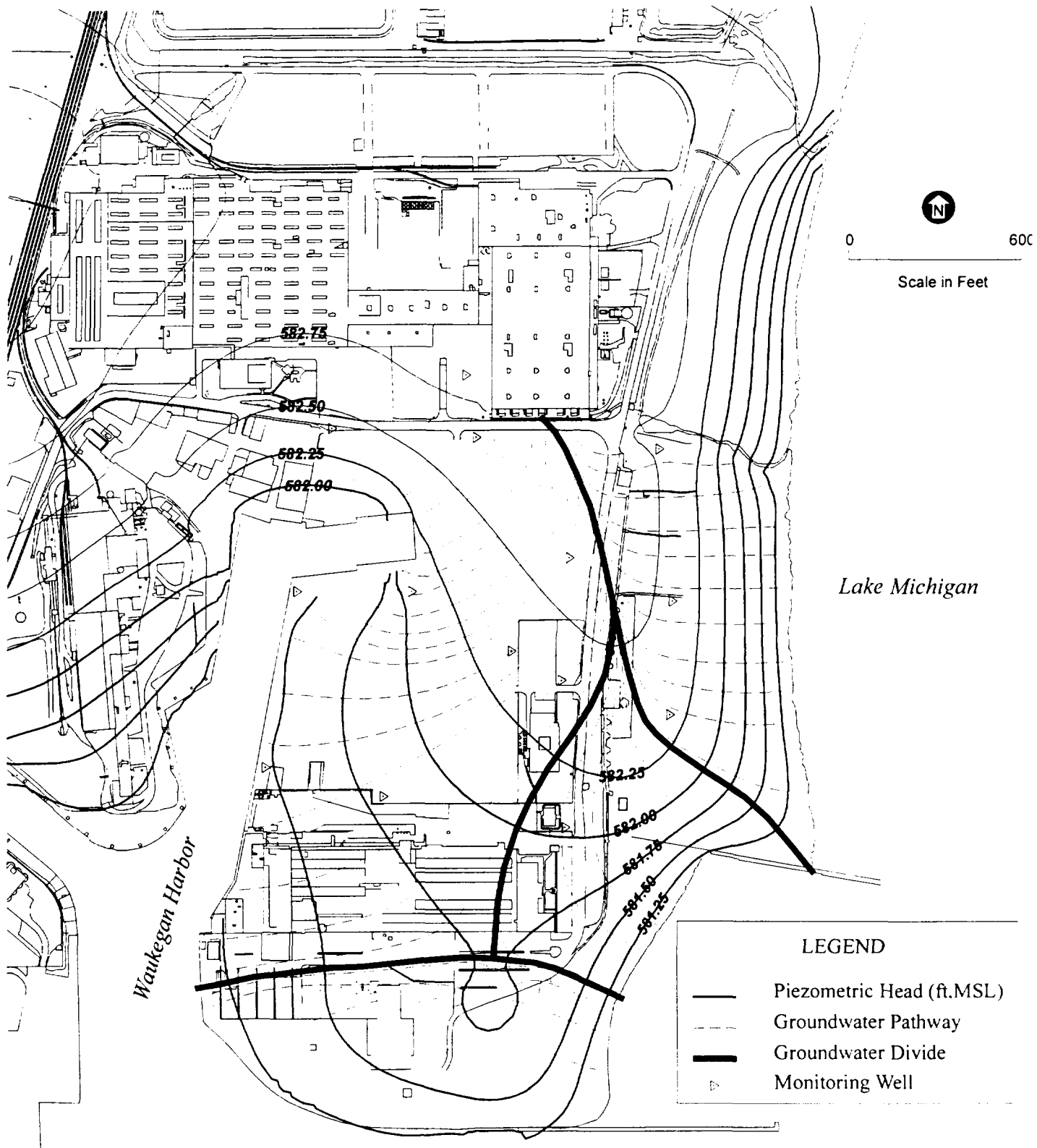
Figure 5-D-13

ALTERNATIVE 3 - REMOVAL (50% INFILTRATION)
Waukegan Manufactured Gas & Coke Plant Site

N

0 ——————— 60

Scale in Feet

Lake Michigan

582.75

582.50

582.00

582.25

582.00

581.75

581.50

581.25

Waukegan Harbor

LEGEND

—————— Piezometric Head (ft,MSL)

.... Groundwater Pathway

━━━━━ Groundwater Divide

▷ Monitoring Well
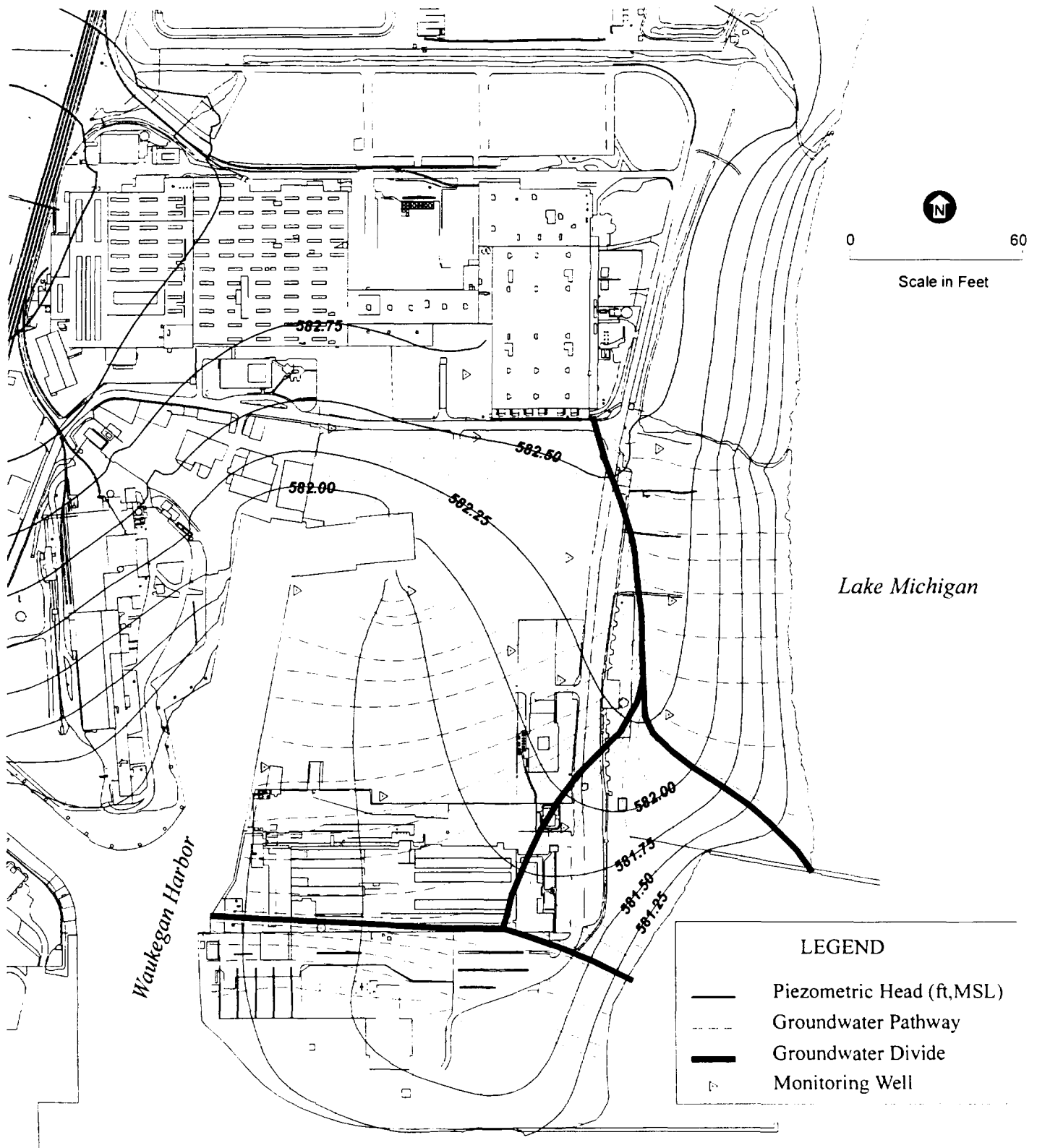
Figure 5-D-14

ALTERNATIVE 3 - REMOVAL (0% INFILTRATION)
Waukegan Manufactured Gas & Coke Plant Site

P 1349003ALT3RMV0 CDR

Ammonia Summary (Lake Discharge)
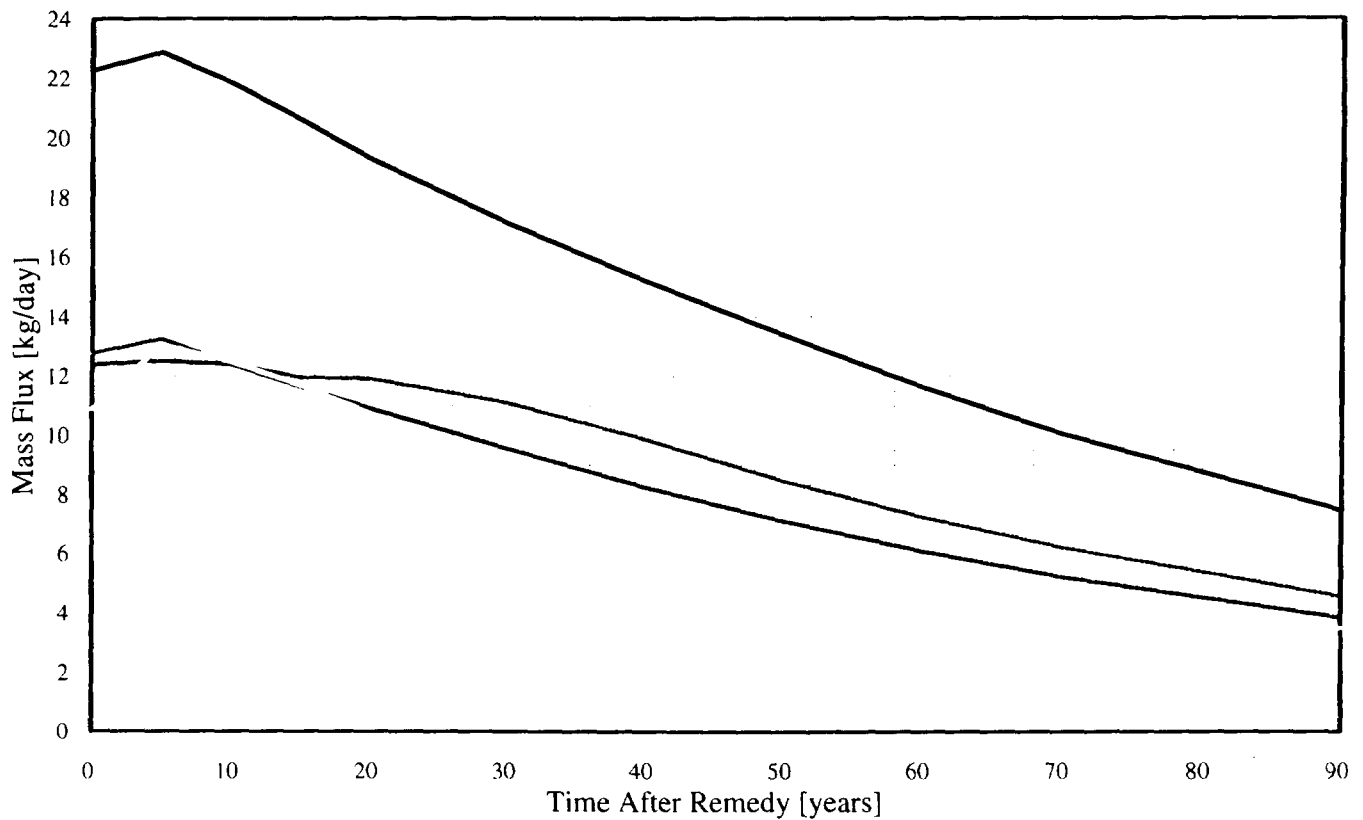
Figure 5-D-15

MASS FLUX COMPARISON FOR
REMEDIAL ALTERNATIVES - LAKE DISCHARGE
AMMONIA SUMMARY
Waukegan Manufactured Gas & Coke Plant Site

Ammonia Summary (Breakwater Discharge)
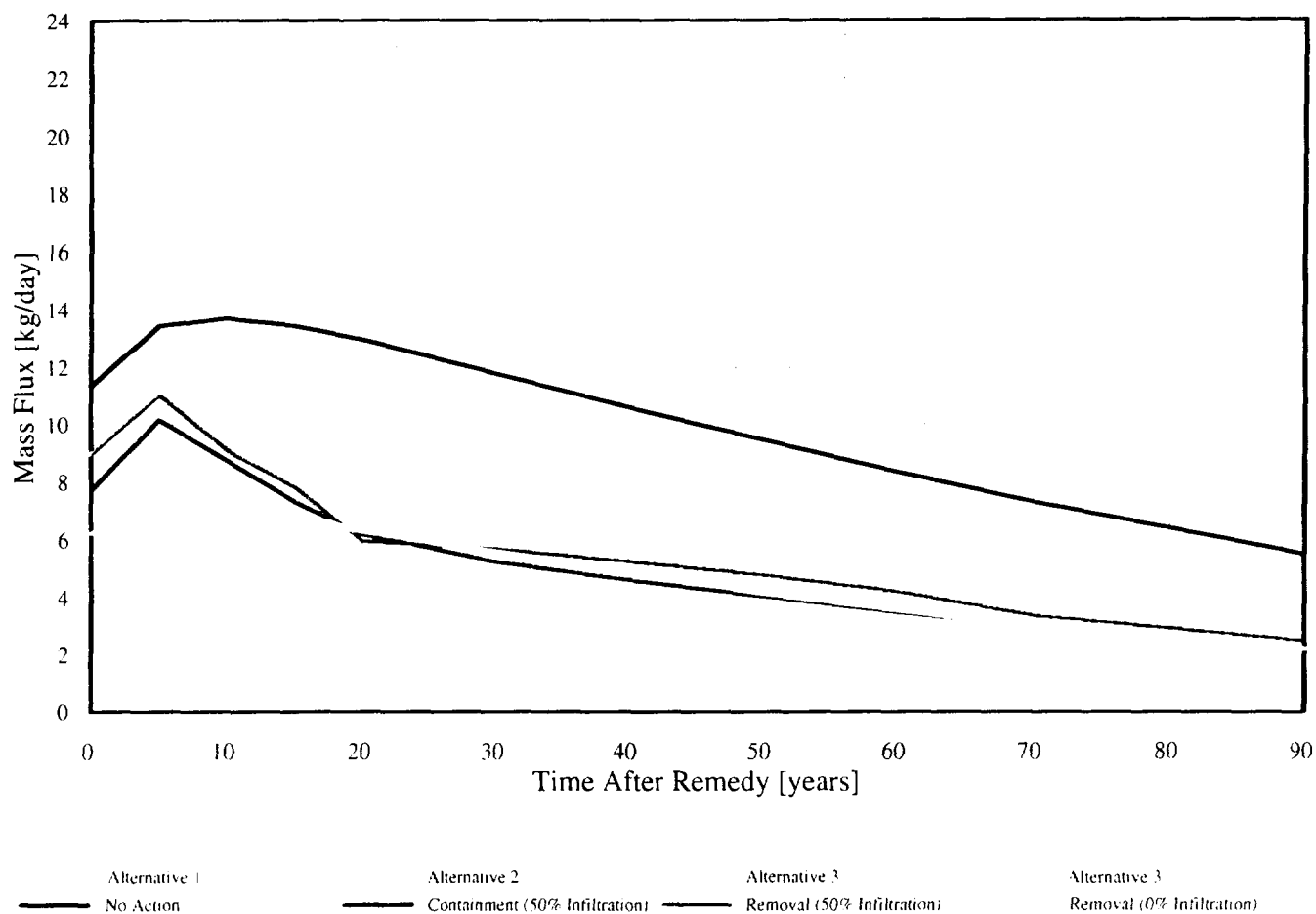
Figure 5-D-16

MASS FLUX COMPARISON FOR
REMEDIAL ALTERNATIVES - BREAKWATER DISCHARGE
AMMONIA SUMMARY
Waukegan Manufactured Gas & Coke Plant Site

Ammonia Summary (Harbor Discharge)
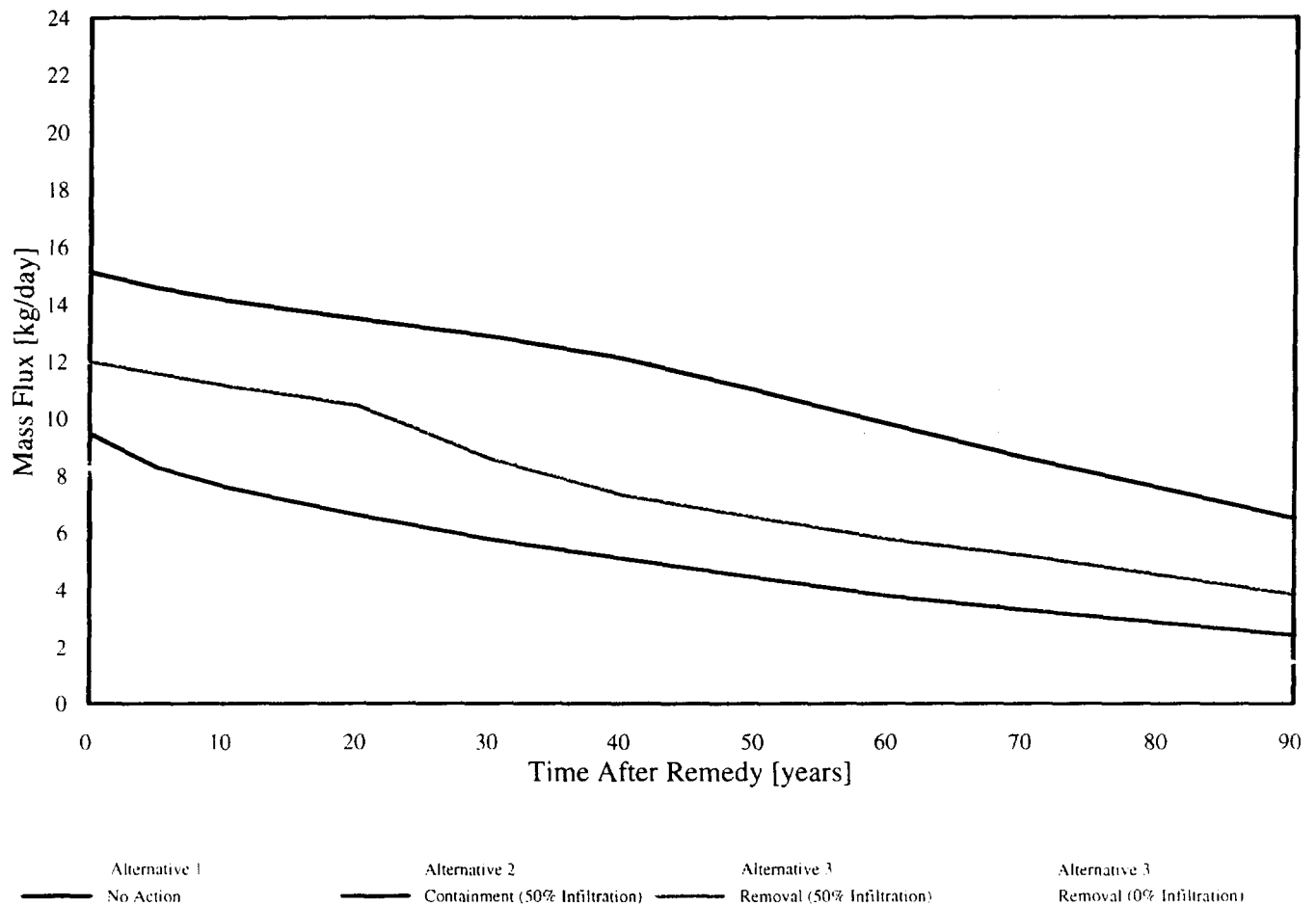
Figure 5-D-17

MASS FLUX COMPARISON FOR
REMEDIAL ALTERNATIVES - HARBOR DISCHARGE
AMMONIA SUMMARY
Waukegan Manufactured Gas & Coke Plant Site

Arsenic Summary (Lake Discharge)
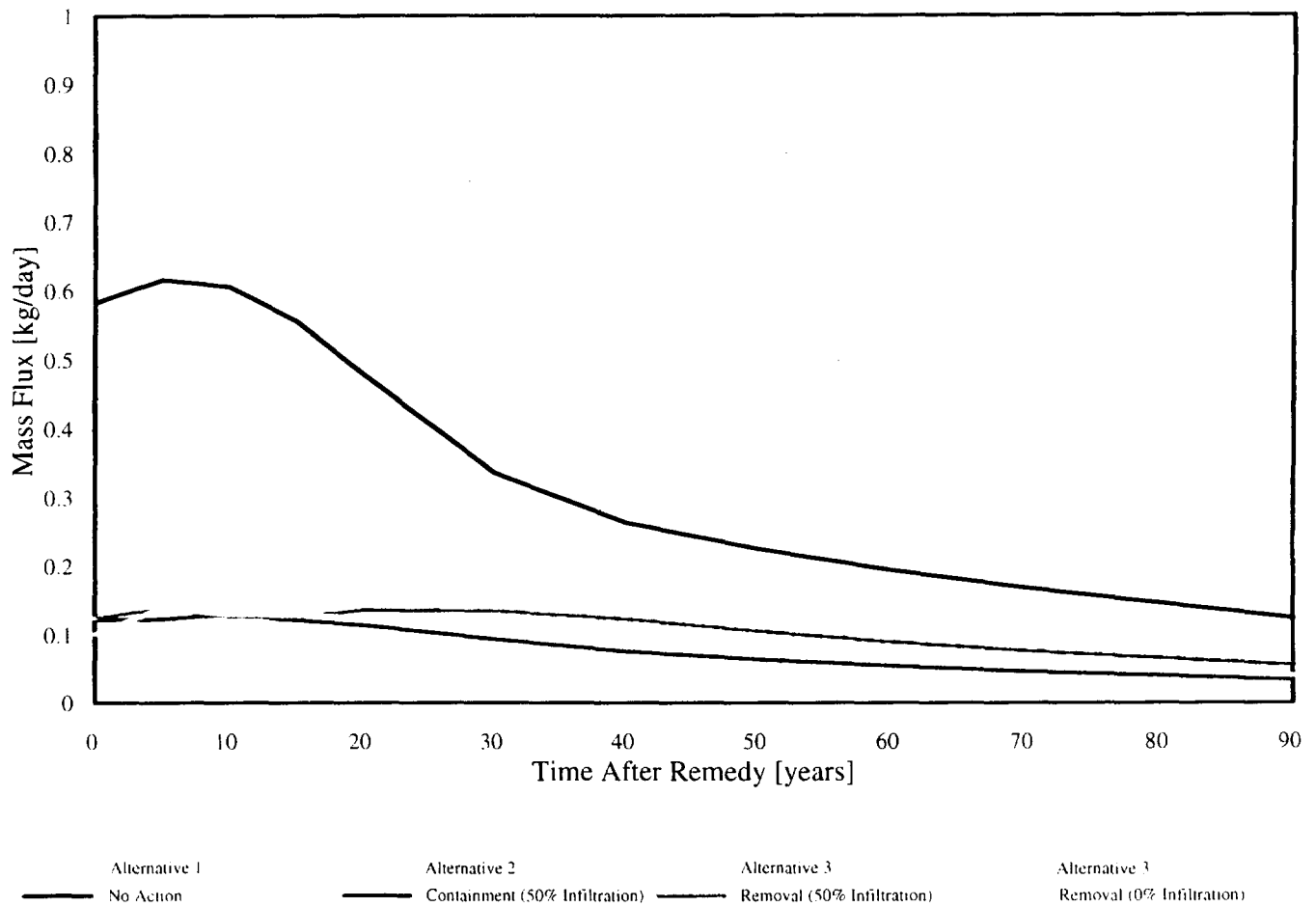
Figure 5-D-18

MASS FLUX COMPARISON FOR
REMEDIAL ALTERNATIVES - LAKE DISCHARGE
ARSENIC SUMMARY
Waukegan Manufactured Gas & Coke Plant Site

Arsenic Summary (Breakwater Discharge)

Mass Flux [kg/day] vs Time After Remedy [years]

Alternative 1	Alternative 2	Alternative 3	Alternative 3
No Action	Containment (50% Infiltration)	Removal (50% Infiltration)	Removal (0% Infiltration)
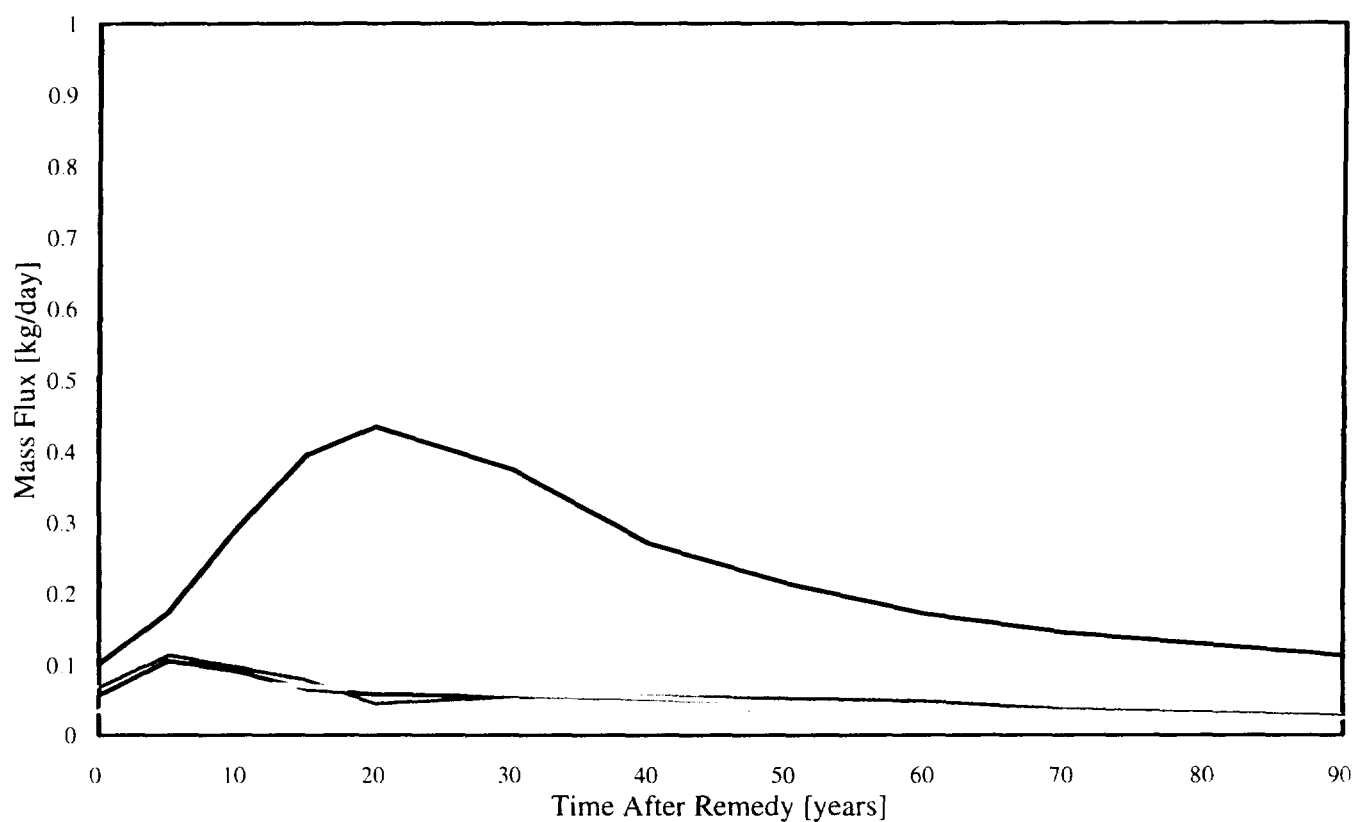
Figure 5-D-19

MASS FLUX COMPARISON FOR
REMEDIAL ALTERNATIVES - BREAKWATER DISCHARGE
ARSENIC SUMMARY
Waukegan Manufactured Gas & Coke Plant Site

Arsenic Summary (Harbor Discharge)

Alternative 1
No Action

Alternative 2
Containment (50% Infiltration)

Alternative 3
Removal (50% Infiltration)

Alternative 3
Removal (0% Infiltration)
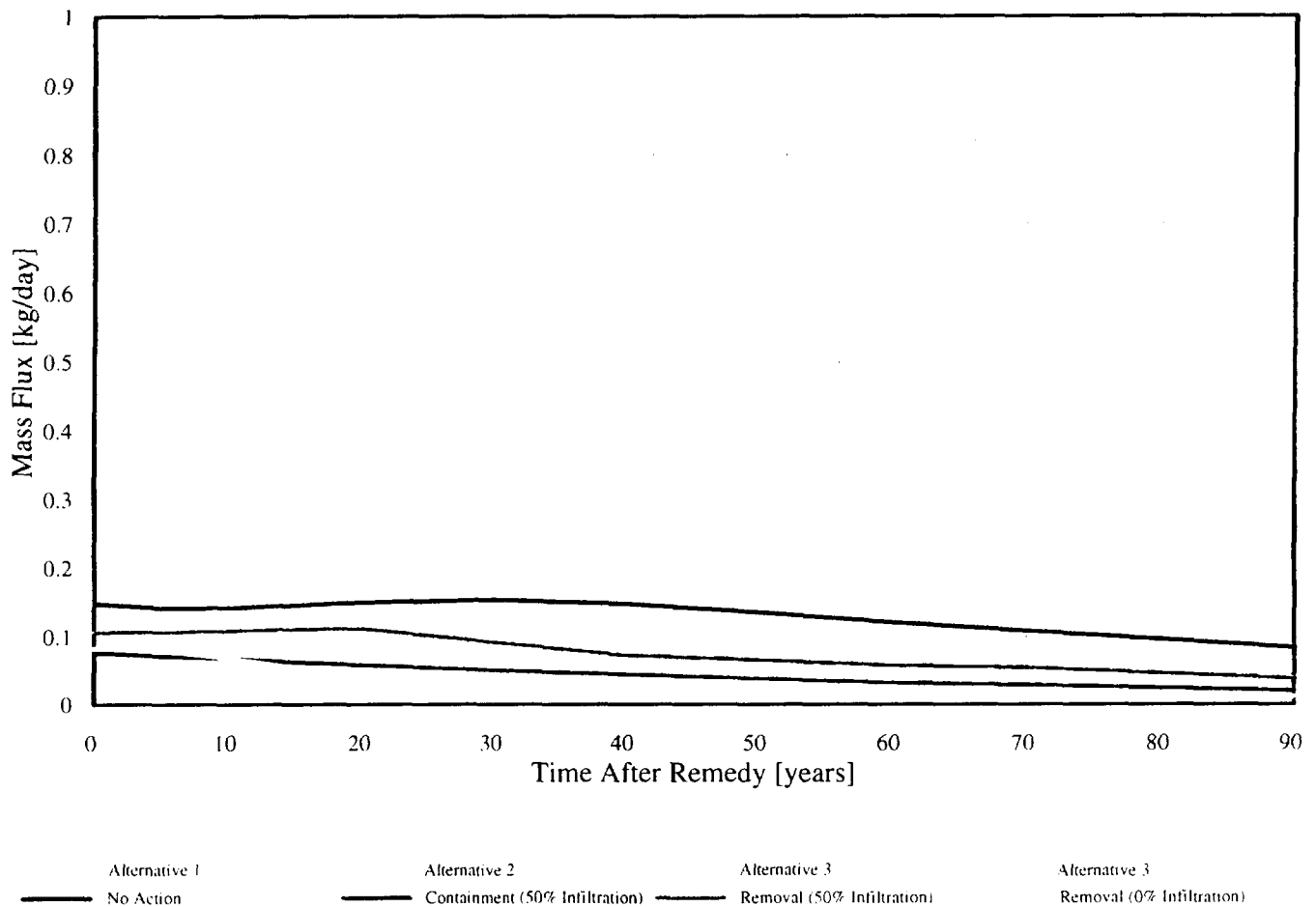
Figure 5-D-20

MASS FLUX COMPARISON FOR
REMEDIAL ALTERNATIVES - HARBOR DISCHARGE
ARSENIC SUMMARY
Waukegan Manufactured Gas & Coke Plant Site

Phenols Summary (Lake Discharge)

Mass Flux [kg/day] vs Time After Remedy [years]

Alternative 1	Alternative 2	Alternative 3	Alternative 3
No Action	Containment (50% Infiltration)	Removal (50% Infiltration)	Removal (0% Infiltration)
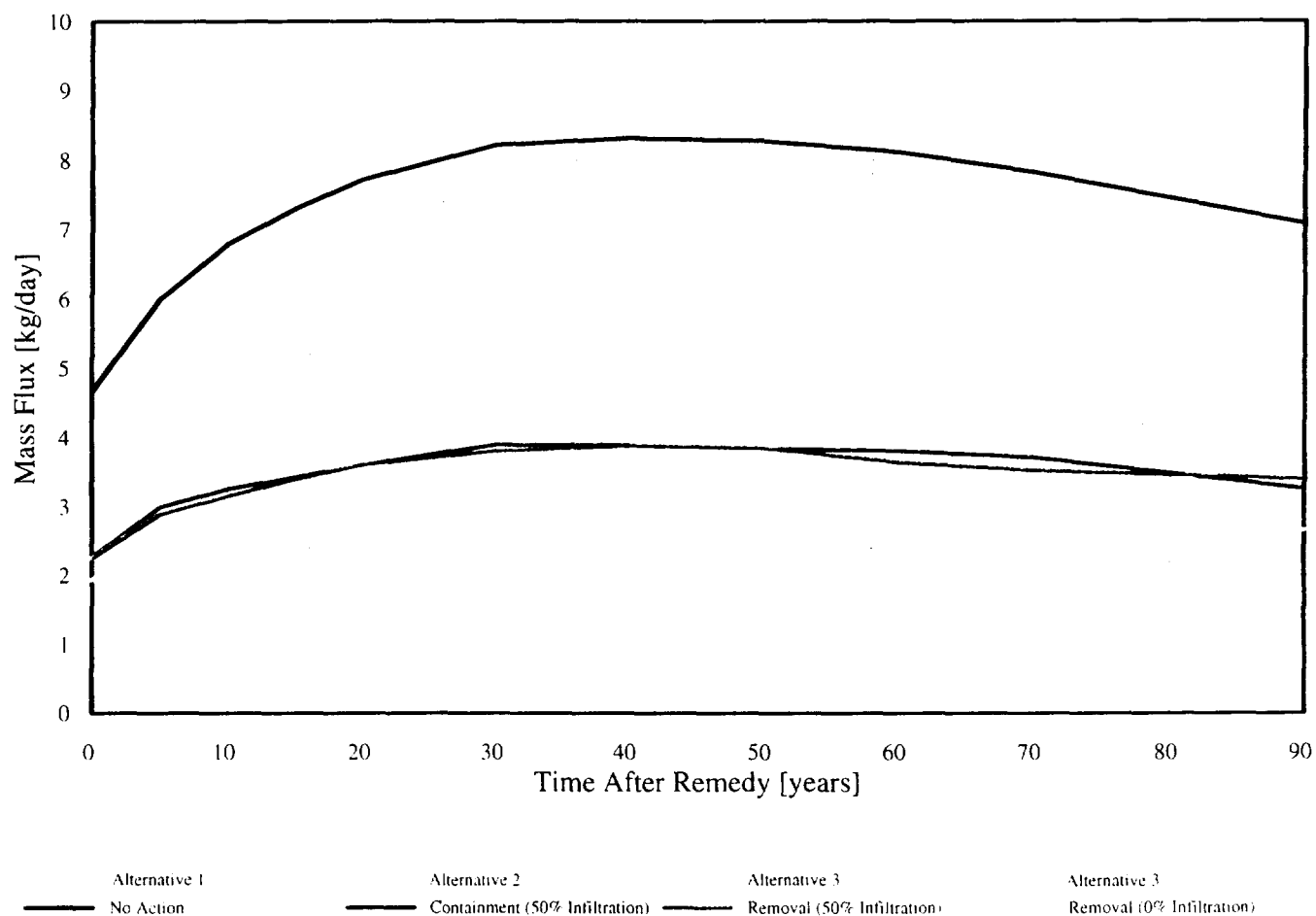
Figure 5-D-21

MASS FLUX COMPARISON FOR
REMEDIAL ALTERNATIVES - LAKE DISCHARGE
PHENOLS SUMMARY
Waukegan Manufactured Gas & Coke Plant Site

Phenols Summary (Breakwater Discharge)

Mass Flux [kg/day] vs Time After Remedy [years]

Alternative 1
—— No Action

Alternative 2
—— Containment (50% Infiltration)

Alternative 3
—— Removal (50% Infiltration)

Alternative 3
Removal (0% Infiltration)
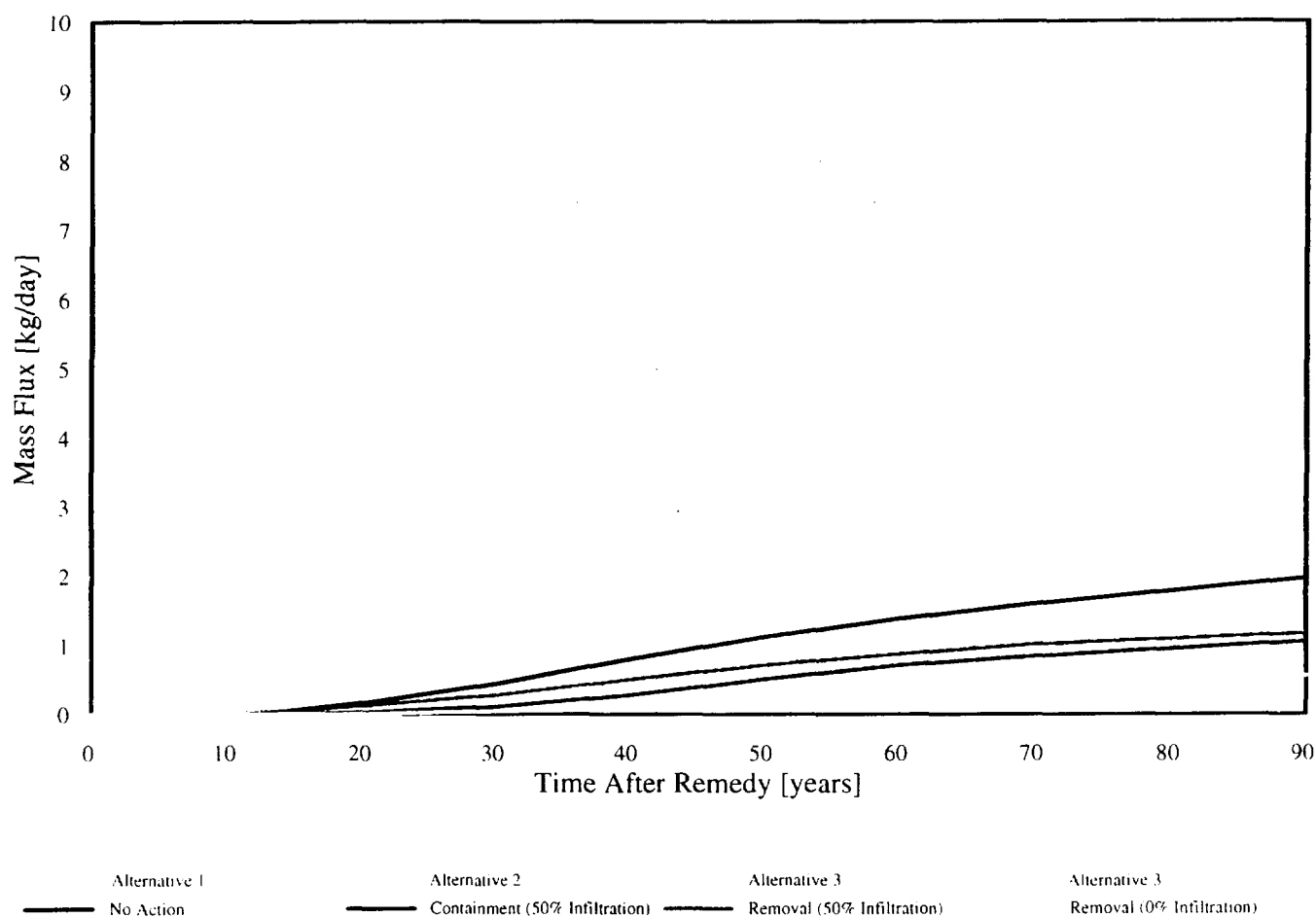
Figure 5-D-22

MASS FLUX COMPARISON FOR
REMEDIAL ALTERNATIVES - BREAKWATER DISCHARGE
PHENOLS SUMMARY
Waukegan Manufactured Gas & Coke Plant Site

Phenols Summary (Harbor Discharge)

Mass Flux [kg/day] vs. Time After Remedy [years]

Alternative 1	Alternative 2	Alternative 3	Alternative 3
No Action	Containment (50% Infiltration)	Removal (50% Infiltration)	Removal (0% Infiltration)
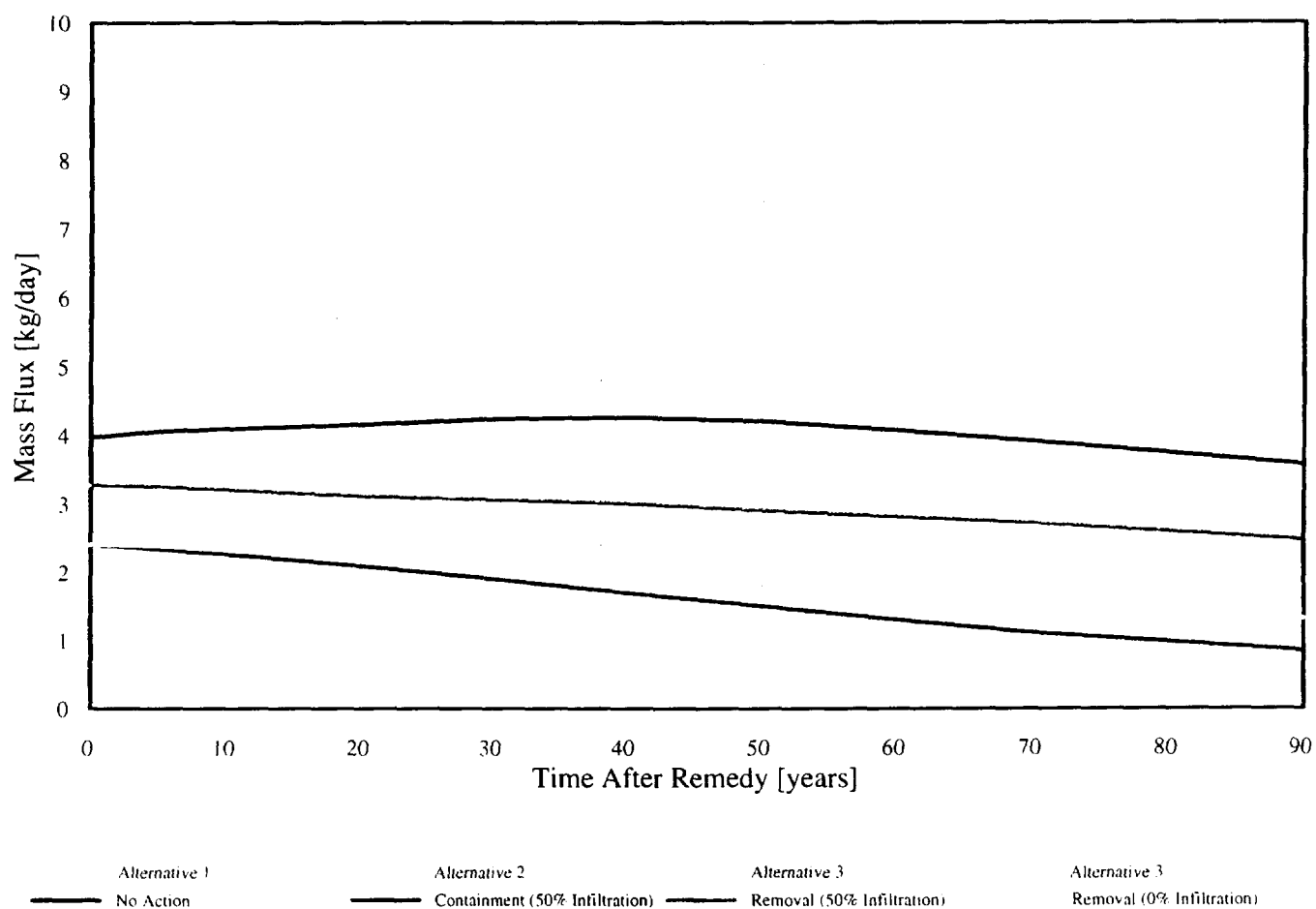
Figure 5-D-23

MASS FLUX COMPARISON FOR
REMEDIAL ALTERNATIVES - HARBOR DISCHARGE
PHENOLS SUMMARY
Waukegan Manufactured Gas & Coke Plant Site

Ammonia Summary (Lake Discharge)

Mass Flux [kg/day] vs. Time After Remedy [years]

| Alternative 1 | Alternative 3 | Alternative 3 |
| No Action | 50% Removal (50% Infiltration) | 85% Removal (50% Infiltration) |
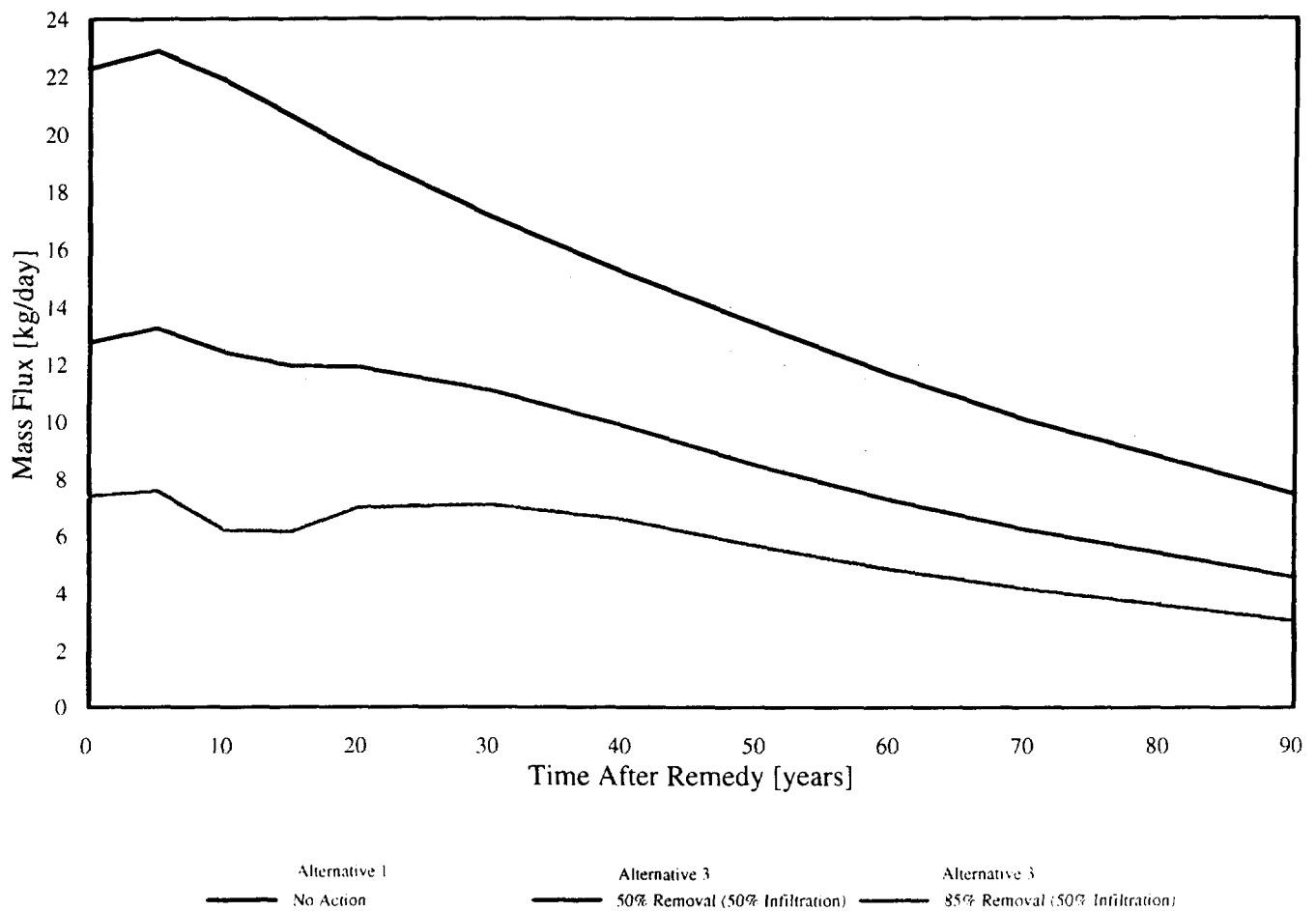
Figure 5-D-24

MASS FLUX COMPARISON FOR
AMMONIA REMOVAL - LAKE DISCHARGE
Waukegan Manufactured Gas & Coke Plant Site

Efficient Approximate Solutions to 1-D Dispersive Transport Equations

C. MAAS

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Recent field tests have revealed that the longitudinal component of the dispersion tensor dominates the transverse components to such an extent that the latter can probably be ignored in many applications of practical interest. Even so, exact analytical solutions to transport equations including sorption, decay and finite front dispersion may be cumbersome, if at all possible. Three different approximate methods, that are easy to evaluate, were tested against exact solutions of contaminant breakthrough, obtained for simple boundary conditions. The first one was Edgeworth's expansion, truncated after the first few terms. This expansion is quite economical, but tends to diverge close to the source of contamination. The second one was a staircase approximation (probably due to Von Mises) to the breakthrough curve, based on matching of moments. This method is elegant and works well, but it requires the evaluation of many moments of the theoretical breakthrough curve. The last one was the incomplete Gamma function, shifted along the time-axis. This approximation proved to be far superior. It requires the evaluation of only four moments (including the zeroth order moment) of a breakthrough curve and shows no tendency to degenerate near the source. In all cases investigated the approximation was already quite acceptable at a travel distance of five times the longitudinal dispersivity, becoming soon indistiguishable from exact solutions. A method is indicated to obtain the parameters of the shifted incomplete Gamma function from any given transport equation. Explicit expressions for these parameters are given for the case of finite front dispersion, first order decay and rate limited sorption under conditions of uniform flow. The formulas are likely to be of good use in non-uniform flow as well. The parameters are cast in forms that are simple functions of the distance traveled. They can be tracked, going along a flow line, just like travel time is tracked in conventional plug flow models.

INTRODUCTION

Current field tests at Borden, Ontario [*Rajaram and Gelhar*, 1991], on Cape Cod, Massachusetts [*Garabedian et al.*, 1991] and in Denmark [*Jensen et al.*, 1993] have revealed that the longitudinal component of the dispersion tensor dominates the transverse components to such an extent that the latter can probably be ignored in many applications of practical interest. This finding regenerates the importance of 1-D models of dispersive transport [*Voss and Knopman*, 1989], which are simple as compared to 3-D models. Even so, exact analytical solutions of contaminant breakthrough along curvilinear flow lines, including such features as sorption, decay and finite front dispersion [*Strack*, 1992] may be cumbersome, if at all possible. In this paper we look for an accurate, *approximate* and uniform solution technique, that applies to a wide variety of 1-D dispersive transport equations and is easy to implement in models that are capable of tracking stream lines.

THE SHAPE OF BREAKTHROUGH CURVES

Conservative Case

We consider dispersion of groundwater to be the result of an ongoing process of convolution (Figure 1). Going along a stream tube, a heterogeneous porous medium is imagined to be made up of a series of subsystems, transmitting a signal. If the subsystems are supposed to be mathematically linear, it is possible to express the relation between an ingoing signal $c_{in}(t)$ and its corresponding outgoing signal $c_{out}(t)$ as a repeated convolution integral

$$c_{out}(t) = \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} ... \int_{-\infty}^{\infty} c_{in}(\tau_1)\, \theta_1(\tau_2 - \tau_1).$$
$$\theta_2(\tau_3 - \tau_2)...\theta_n(t - \tau_n)\, d\tau_1\, d\tau_2....d\tau_n \qquad (1)$$

where t is time and θ_i is the 'impulse response' of the ith subsystem. We assume the impulse responses to be independent of the signal; hence we regard them as medium characteristics. When the input signal $c_{in}(t)$ is taken to be Dirac's delta function, then the output signal $c_{out}(t)$ reveals the impulse response function $\theta(t)$ of the composite system:

$$\theta(t) = \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} ... \int_{-\infty}^{\infty} \theta_1(\tau_2 - \tau_1).$$
$$\theta_2(\tau_3 - \tau_2)...\theta_n(t - \tau_n)\, d\tau_1\, d\tau_2...d\tau_n \qquad (2)$$

Breakthrough curves are defined as the integrals with respect to time of $\theta(t)$. We pose ourselves the question to what extent the shape of a breakthrough curve depends on the particulars of the functions $\theta_i(t)$.

One may notice that the functions $\theta_i(t)$ must be positive definite by their physical nature and they must have unit area. It is known from statistics that convolution of n such functions is mathematically similar to adding up n random variables [*Springer*, 1979, p 47]. In this analogy the characteristics $\theta_i(t)$ correspond to probability density functions. Hence, although our model is purely deterministic, we may apply the Central Limit Theorem, to state

Fig. 1: Porous medium considered as a series of linear systems.

that the impulse response $\theta(t)$ will tend to become a Gauss-curve, as n increases, no matter what shapes the functions $\theta_i(t)$ assume (as long as they satisfy the 'Lindeberg conditions' [e.g. *Von Mises*, 1964]). The breakthrough curve, being the integral of the impulse response, will tend to obtain the shape of an error-function. The variance of the limiting Gauss-curve is known to equal the sum of the variances of the functions $\theta_i(t)$, so the limiting shape of the output signal appears to depend *only on the variances* of the functions $\theta_i(t)$, no matter how these functions behave otherwise. (It should raise no surprise, therefore, that almost any model of dispersion comes up with a Gaussian limit).

In an earlier phase, when the Gauss-curve has not yet been established, we have Edgeworth's asymptotic expansion of a random variable [*Abromowitz and Stegun*, 1968, p 935]: Let θ_i (i = 1, 2, ..., n) be n independent random variables with mean μ_i, variance σ_i^2, and cumulants $K_{j,i}$. (See Appendix 1 for a definition of cumulants). Then

$$\theta(t) =$$
$$[1 - \{\frac{1}{3!}K_3\frac{d^3}{dt^3}\} + \{\frac{1}{4!}K_4\frac{d^4}{dt^4} + \frac{1}{2!}(\frac{1}{3!}K_3)^2\frac{d^6}{dt^6}\} - \{...\} + ...].$$
$$\frac{1}{\sqrt{2\pi\sigma^2}}\exp\{-\frac{(t-\mu)^2}{2\sigma^2}\} \qquad (3)$$

Here,

$$\mu = \sum_1^n \mu_i$$
$$\sigma^2 = \sum_1^n \sigma_i^2 \qquad (4)$$
$$K_j = \sum_1^n K_{j,i}$$

where n is the number of subsystems. It follows from (4) that the mean, the variance and the (other) cumulants of $\theta(t)$ are proportional to n, the number of systems passed by the transmitted signal.

The terms in (3) are so grouped that their order decreases with increasing n, such that the first term within braces is proportional to $1/\sqrt{n}$, the second term within braces is proportional to $1/n$, etc. They tend to disappear successively with increasing n, such that the first term within braces is the last to vanish, by which time the shape of $\theta(t)$ has become Gaussian.

Non-Conservative Case

The above analogy between impulse responses and probability density functions applies to conservative systems, where the individual impulse responses $\theta_i(t)$ have unit areas. This is no longer the case in non-conservative systems. Non-conservative impulse responses can be normalized, however, according to

$$\theta_i^N(t) = \frac{\theta_i(t)}{A_i} \qquad (5)$$
$$A_i = \int_{-\infty}^{\infty}\theta_i(t)dt$$

The normalized impulse responses $\theta_i^N(t)$ do have unit area. Writing (2) as

$$\theta(t) = \prod_1^n A_i \int_{-\infty}^{\infty}\int_{-\infty}^{\infty}...\int_{-\infty}^{\infty}\theta_1^N(\tau_2-\tau_1). \qquad (6)$$
$$\theta_2^N(\tau_3-\tau_2)...\theta_n^N(t-\tau_n)\,d\tau_1\,d\tau_2...d\tau_n$$

it can be seen that the limit theorems of statistics apply to non-conservative dispersive transport as well, provided that the limits are multiplied by $\prod A_i$. It is clearly possible to extend Edgeworth's expansion for the non-conservative case to

$$\theta(t) =$$
$$A [1 - \{\frac{1}{3!}K_3\frac{d^3}{dt^3}\} + \{\frac{1}{4!}K_4\frac{d^4}{dt^4} + \frac{1}{2!}(\frac{1}{3!}K_3)^2\frac{d^6}{dt^6}\} - \{...\} + ...].$$
$$\frac{1}{\sqrt{2\pi\sigma^2}}\exp\{-\frac{(t-\mu)^2}{2\sigma^2}\} \qquad (7)$$

where

$$A = \prod_1^n A_i \qquad (8)$$

A is the area of $\theta(t)$. Notice that $\ln(A)$ is proportional to n, the number of subsystems passed by the signal. Consequently, we may conclude that in the special case of identical subsystems (uniform flow in homogeneous media) the growth or decay of a signal must be an exponential function of the distance traveled.

Parallel stream lines

Figure 1 may have raised the suggestion that, for the convolutional model to apply, it is necessary that two adjacent subsystems transfer a signal at a single point of contact. This is not necessarily the case, as the following example shows. Suppose that an originally straight front of some intruding contaminant breaks up in two parts after traveling a distance ℓ (Figure 2), one part of width p traveling on at velocity v_p and the other, having width q, continuing at v_q. Suppose that this process repeats itself every time another distance ℓ has been covered, thus producing ever thinner fingers. Although highly schematized this is not at all unlike the way actual fronts progress through heterogeneous porous media. For comparison Figure 3 shows the deformation of a moving front in a simulated heterogeneous column. The breakthrough curve at a distance $n\ell$ from the origin is a staircase function, whose steps are given by the binomial distribution:
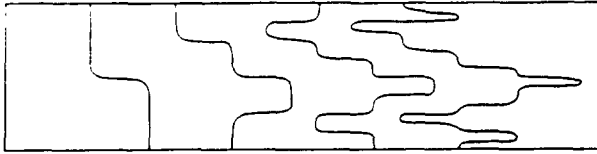
Fig. 2: Breaking up of a front by the binomial process.

Fig. 3: Breaking up of a front in a simulated heterogeneous column. (Courtesy J.C. Panda, Univ. of Minn.)

$$c_j = \binom{n}{j} p^{n-j} q^j \quad (j=0,n) \tag{9}$$

[*Von Mises*, 1964, p 168]. The breakthrough time of the jth step is given by

$$t_j = (n-j)\frac{1}{v_p} + j\frac{1}{v_q} \tag{10}$$

Equation (9) being a probability density function the Central Limit Theorem guaranties convergence to the Gaussian limit.

It is nevertheless thinkable that neighboring fingers exchange contaminated particles by diffusion or transverse dispersion. Besides the model of Figure 1 we also examined series of systems with internal transverse interaction and multiple points of transfer (Figure 4). We summarize our results briefly, for future reference:

If the individual systems had n parallel subsystems, then the impulse response of the composite system appeared to consist (asymptotically) of n superimposed Gauss curves. Each Gauss curve contained a fixed amount of mass, traveled at its own characteristic velocity, and spread at its own characteristic rate. The fastest Gaussian appeared to have the slowest rate of spreading, such that (after an initial transitional phase) the composite impulse response had the appearance of a Gauss curve, followed by a very long tail of almost zero concentration. The amount of mass carried by the tail was constant, however. Simulated column experiments seemed to confirm this type of
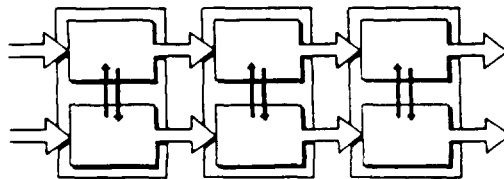
Fig. 4: Series of systems with transverse interaction.

tailing [*J.C. Panda*, Univ. of Minn.]. (It is often recorded, in reports on field experiments, that not all of the injected tracer could be recovered. Might this be a cause)?

APPROXIMATE SOLUTIONS TO 1-D DISPERSIVE TRANSPORT EQUATIONS

Three approximations

If the convolutional model of dispersive transport is correct, then (7) must be a solution to any (linear) 1-D dispersive transport equation, provided that the series converges. In its present form this equation contains an infinite number of parameters. However, since most of the terms within braces are to vanish soon, one may expect that a truncated version of (7) may serve as a large time solution. This suggests that, in stead of solving the breakthrough curve from a differential equation, it might be possible (and hopefully easier) to calculate a few cumulants and then evaluate (7). The question how to obtain cumulants, given a differential equation, will be addressed in Section 3.2. We present some results first. Expression (7) (integrated with respect to time) was applied to a number of dispersive transport equations for which exact solutions were at hand (for confirmation), ranging from dispersion only to equations including rate limited sorption, first order decay and finite front velocity. Figure 5 shows the results for the classical 1-D Convection Dispersion Equation. This example made use of three terms of expansion (7). The truncated series appears to oscillate at shorter distances from the source. We encountered this phenomenon in all cases investigated, and this behavior worsened when more terms were added. There exist convergence tests for Edgeworth's series [*Von Mises*, 1931] but they require a priori knowledge of the exact solution, which is contradictory to our goal. In the present example the approximation was found to become acceptable at $x \approx 20 \, \alpha_L$, which appeared to be rather
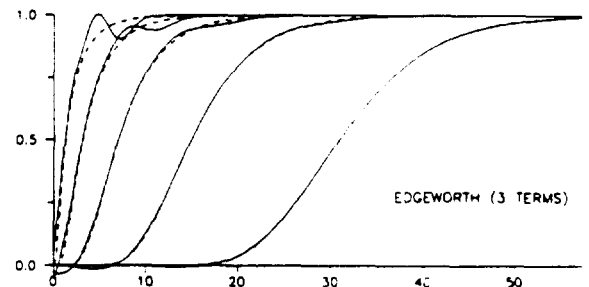
Figure 5: Convergence of Edgeworth's expansion (first three terms) to an exact solution of the Convection Dispersion Equation. Horizontal axis: dimensionless time (vva_L). Vertical axis: dimensionless concentration. Breakthrough curves are shown at dimensionless distances (x/a_L) 2, 4, 8, 16, 32.

3

typical. (In practice α_L may range from a few centimeters to several kilometers [Gelhar et al., 1992]).

As an alternative to this approach, it is possible to approximate a breakthrough curve by an n-step staircase function, given its first 2n moments. (There exists a one-to-one correspondence between moments and cumulants, see Appendix 1). The appealing procedure is given in detail by [Von Mises, 1964]. We confine ourselves, in this paper, to the recipe:

Let M_0 through M_{2n-1} be the first 2n moments of a breakthrough curve. We want to determine the n-step staircase function that has precisely these moments. The abscissa of the steps are $a_1, a_2,......, a_n$ and their magnitudes are $A_1, A_2,...... A_n$. This problem can be shown to have a unique solution, that is: the a_i and A_i are single-valued and the A_i are non-negative. In order to find them, calculate the auxiliary constants c_0 to c_{n-1} from

$$\begin{bmatrix} M_0 & M_1 & ... & M_{n-1} \\ M_1 & M_2 & ... & M_n \\ . & . & ... & . \\ . & . & ... & . \\ M_{n-1} & M_n & ... & M_{2n-2} \end{bmatrix}\begin{bmatrix} c_0 \\ c_1 \\ . \\ . \\ c_{n-1} \end{bmatrix} = -\begin{bmatrix} M_n \\ M_{n-1} \\ . \\ . \\ M_{2n-1} \end{bmatrix} \quad (11)$$

The square matrix in the left hand side is of the Toeplitz-type, for which very efficient numerical routines are readily available [Press et al. 1992]. The constants a_i are now determined iteratively as the roots of the polynomial

$$t^n + \sum_{i=0}^{n-1} c_i t^i = 0 \quad (12)$$

(Root-finding routines are also to be found in [Press et al., 1992]). Once the a_i are known, the A_i can be computed from

$$\begin{bmatrix} 1 & 1 & ... & 1 \\ a_1 & a_2 & ... & a_n \\ . & . & ... & . \\ . & . & ... & . \\ a_1^{n-1} & a_2^{n-1} & ... & a_n^{n-1} \end{bmatrix}\begin{bmatrix} A_1 \\ A_2 \\ . \\ . \\ A_n \end{bmatrix} = \begin{bmatrix} M_1 \\ M_2 \\ . \\ . \\ M_n \end{bmatrix} \quad (13)$$

Here appears a Vandermonde-matrix, which can be handled very efficiently, too (refer once more to [Press et al., 1992]). Figure 6 (left) gives an example of a breakthrough curve approximated by a staircase function. It shows that the true breakthrough curve cuts all of the steps and rises. This is not a coincidence: [Von Mises, 1964] proves it to be a rule. In fact, the steps and rises are cut almost in the middle, such that the middle points
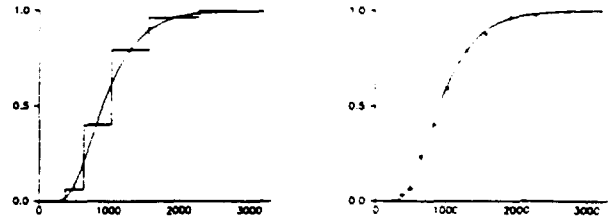
Fig. 6: A breakthrough curve approximated by a staircase function (left) and by the midpoints of the steps and rises of the stairs (right), resp.

give a fair impression of the breakthrough curve. This is illustrated by Figure 6 (right). Figure 7 shows Von Mises' method, compared with solutions of the CDE that were used before to demonstrate Edgeworth's expansion (Figure 5). Unlike Edgeworth's expansion, Von Mises' method shows no tendency to degenerate near the source, but the number of midpoints that can be evaluated without numerical problems, tends to be restricted. It was also found that a substantial part of the calculated steps do not contribute to the picture, as they occur - roughly speaking - either before or after breakthrough.

A third method of approximation of breakthrough curves derives from the mixing reservoirs model (Figure 8). It is supposed that all particles entering a reservoir are instantaneously and completely mixed therein, which can be achieved by constant and thorough stirring of the reservoir contents. The response of a single reservoir to an impulsive input is known to be

$$\theta(t) = ae^{-at} \quad (t \ge 0) \quad (14)$$

where a is a reservoir characteristic. The response of the nth reservoir is found by n-fold convolution of $\theta(t)$:

$$\theta(t) = \frac{a^n t^{n-1}}{(n-1)!}e^{-at} \quad (t \ge 0) \quad (15)$$

which is the Gamma-distribution. The convolutional process ensures that the limiting shape, as n becomes
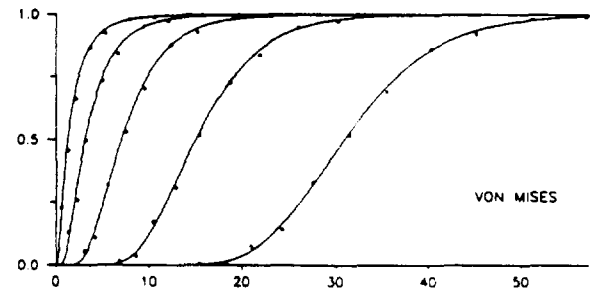
Fig. 7: Von Mises' approximation of breakthrough curves according to the CDE. Drawn lines are exact. All specifications conform Figure 5.
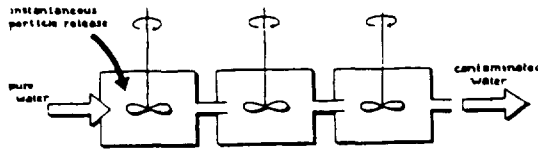
Fig. 8: The mixing reservoirs model.

large, will be a Gauss-curve. Although, in the model of Figure 8, n is a discrete number, it is possible to interpolate smoothly between any two integer values of n by generalizing $(n-1)!$ to $\Gamma(n)$ [Abramowitz and Stegun, 1968, p 255]:

$$\theta(t) = \frac{a^n t^{n-1}}{\Gamma(n)} e^{-at} \quad (t \geq 0) \qquad (16)$$

This function was mentioned by Jury [Jury and Roth, 1990] as a candidate to characterize travel time distributions in groundwater flow. As an approximate solution to dispersive transport equations the degrees of freedom of (16) are very scarce: two parameters, a and n, allow only for the matching of the mean and the variance. A third degree of freedom can be introduced by allowing for a shift along the t-axis:

$$\theta(t) = \frac{a^n (t-b)^{n-1}}{\Gamma(n)} e^{-a(t-b)} \quad (t \geq b) \qquad (17)$$

($\theta(t)$ is understood to be zero if $t < b$). It will be seen in a future paper that this shift in time has a physical interpretation: it corresponds to the breakthrough time of the first contaminated particle. Formula (17) is *Pearson's type III* distribution. The corresponding breakthrough curve is its integral with respect to time:

$$\theta(t) = A \frac{a^n}{\Gamma(n)} \int_b^t (\tau-b)^{n-1} e^{-a(\tau-b)} d\tau \quad (t \geq b) \qquad (18)$$

which is the *Incomplete Gamma-function*, shifted along the t-axis by an amount b. Algorithms can be found in [Press et al., 1992]. Notice that we added a factor A to allow for non-unitary areas of the impulse response func-
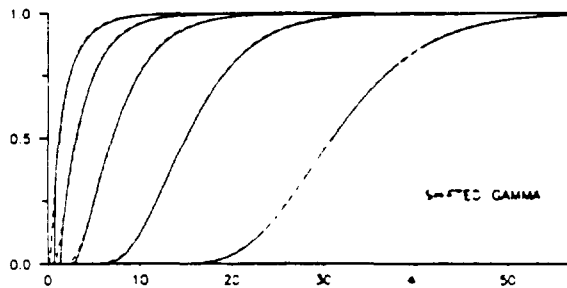
Fig. 9: Exact solutions to the CDE (dashed) approximated by the shifted incomplete Gamma function (drawn) All specifications conform Figure 5

tions. The three parameters a, n, and b can be shown to relate to the first three moments M_1, M_2^c, and M_3^c of $\theta(t)$ according to

$$a = 2\frac{M_2^c}{M_3^c} \qquad n = 4\frac{(M_2^c)^3}{(M_3^c)^2} \qquad b = M_1 - 2\frac{(M_2^c)^2}{M_3^c} \qquad (19)$$

Figure 9 shows the shifted Incomplete Gamma-function applied to the CDE. In all cases investigated this approach appeared to be superior to the former two. It shows none of the wavy behavior of Edgeworth and requires far less moments than Von Mises.

PULLING CUMULANTS/MOMENTS FROM A DIFFERENTIAL EQUATION (Uniform Flow)

All three approximations require expressions for the cumulants or for the moments of a breakthrough curve (which comes down to the same, because of the 1-to-1 correspondence between them [Appendix 1]). The usefulness of the method depends fully on our ability to extract these characteristics from a given differential equation, without having to find an exact solution. There exist various ways of attack, the choice of which depends on the number of cumulants/moments wanted. As the shifted incomplete Gamma-function was found to be particularly useful, we concentrate on a method that is economical if only a few moments are needed (in this case the area A of the impulse response, the mean or first moment M_1, the variance or second central moment M_2^c and the third central moment M_3^c). Consider the differential equation for convection and dispersion including decay [Lapidus and Amundsen, 1952]:

$$\alpha_L v \frac{\partial^2 c}{\partial x^2} - v \frac{\partial c}{\partial x} = \frac{\partial c}{\partial t} + \lambda c \qquad (20)$$

where α_L - dispersivity, v - velocity, c - concentration and λ - decay constant. Using the definition of moments (Appendix 1) and integrating by parts it is easily checked that

$$\int_0^\infty t^n \frac{\partial c(t)}{\partial t} dt = \begin{cases} -nM_0M_{n-1} & (n>1) \\ -M_0 & (n=1) \\ 0 & (n<1) \end{cases} \qquad (21)$$

where M_0 is the zeroth order moment, corresponding to the area A of the impulse response (see Appendix 1). First integrate all terms of the differential equation from zero to infinity. It follows that

$$\alpha_L v \frac{d^2 M_0}{dx^2} - v \frac{dM_0}{dx} = \lambda M_0 \qquad (22)$$

which (under obvious boundary conditions) yields

5

$$M_0 = \exp \left\{ \frac{x}{2\alpha_L} - \frac{x}{2\alpha_L} \sqrt{1 + 4\alpha_L \lambda/v} \right\} \qquad (23)$$

The second step involves multiplication of all terms of (20) by t and integration from zero to infinity, giving

$$\alpha_L v \frac{d^2 M_0 M_1}{dx^2} - v \frac{dM_0 M_1}{dx} = -M_0 + \lambda M_0 M_1 \qquad (24)$$

which can be simplified to

$$\alpha_L v \frac{d^2 M_1}{dx^2} - v \sqrt{1 + 4\alpha_L \lambda/v} \frac{dM_1}{dx} = -1 \qquad (25)$$

by virtue of (22) and (23). We conclude from (4) that $M_1 :: x$ (because the mean μ, being identical to M_1, was found to be proportional to the number of systems passed) hence its second derivative vanishes. The remaining differential equation gives

$$M_1 = \frac{x}{v\sqrt{1 + 4\alpha_L \lambda/v}} \qquad (26)$$

In a like manner it is derived that

$$\alpha_L v \frac{d^2 M_0 M_2}{dx^2} - v \frac{dM_0 M_2}{dx} = -2M_0 M_1 + \lambda M_0 M_2 \qquad (27)$$

or, using (22), (23) and (25)

$$\alpha_L v \frac{d^2 M_2}{dx^2} - v \sqrt{1 + 4\alpha_L \lambda/v} \frac{dM_2}{dx} = -2M_1 \qquad (28)$$

Taking recourse to the relation

$$M_2 = M_2^c + M_1^2 \qquad (29)$$

(see Appendix 1) it follows that

$$\alpha_L v \frac{d^2 M_2^c}{dx^2} - v \sqrt{1 + 4\alpha_L \lambda/v} \frac{dM_2^c}{dx} = -\frac{2\alpha_L}{v(1 + 4\alpha_L \lambda/v)} \qquad (30)$$

The second derivative vanishes again [see (4), with $\sigma^2 = M_2^c$], so

$$M_2^c = \frac{2\alpha_L x}{v^3 (1 + 4\alpha_L \lambda/v)^{3/2}} \qquad (31)$$

The third central moment M_3^c is found along similar lines:

$$M_3^c = \frac{12\alpha_L^2 x}{v^5 (1 + 4\alpha_L \lambda/v)^{5/2}} \qquad (32)$$

Figure 10 (lower graph) shows some resulting approximate breakthrough curves for a deliberate choice of the decay constant λ. Also shown are Edgeworth's and Von
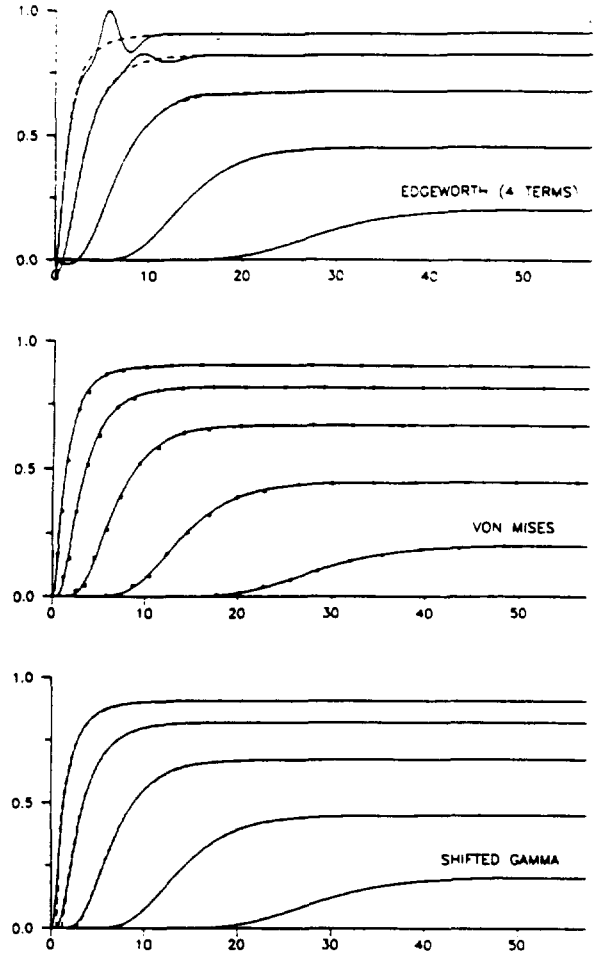
Fig. 10: Various approximations to the CDE with a decay term. Here, $\lambda = .0525\, v/\alpha_L$. Other specifications conform Figure 5.

Mises' approximations.

Strack's Dispersion Equation (uniform flow)

We have tested the performance of the shifted incomplete gamma function for various other transport equations as well, always finding the approximation acceptable already at ca $x = 5\, \alpha_L$ or earlier, and soon thereafter becoming indistinguishable from exact solutions.

The most complete set of transport equations investigated was the following, which includes decay, rate limited sorption and 'Strackian' dispersion:

$$\alpha_L v^2 \frac{\partial^2 c}{\partial x^2} - \beta v \frac{\partial^2 c}{\partial x \partial t} - \beta \frac{\partial^2 c}{\partial t^2} - v^2 \frac{\partial c}{\partial x} - v \frac{\partial c}{\partial t} =$$
$$- \kappa_2 \beta \frac{\partial c_s}{\partial t} + (\kappa_1 + \lambda)\beta \frac{\partial c}{\partial t} - v \kappa_2 c_s + v(\kappa_1 + \lambda)c \qquad (33)$$

and

$$\frac{\partial c_s}{\partial t} = \kappa_1 c - (\kappa_2 + \lambda)c_s \qquad (34)$$

where α_L – longitudinal dispersivity [L], v – 'actual' groundwater velocity [L/T], c – concentration [M/L^3], β – coefficient due to [Strack, 1992] [L], $\kappa_{1,2}$ – coefficients allowing for various interpretations, to be explained below [T^{-1}], c_s – ratio of sorbed mass to pore volume [M/L^3], λ – decay constant [T^{-1}]. The parameters κ_1 and κ_2 govern the sorption rate and the equilibrium distribution of the contaminant between the solute and a sorbing medium. The formulation of (33) and (34) is sufficiently general to allow for various physical interpretations (Appendix 2). Strack's β-coefficient controls the velocity of the quickest fluid particles. As there is no place in this paper to explain the theory, we refer to [Strack, 1992]. The reader may wish to ignore the influence of this coefficient by putting $\beta = 0$ in the sequel. It is possible to eliminate c_s from (33) and (34) to obtain a single differential equation in c:

$$\alpha_L v^2 \frac{\partial^3 c}{\partial x^2 \partial t} - \beta v \frac{\partial^3 c}{\partial x \partial t^2} - \beta \frac{\partial^3 c}{\partial t^3} + \alpha_L v^2 \kappa_2^* \frac{\partial^2 c}{\partial x^2} - $$

$$v(v + \beta \kappa_2^*) \frac{\partial^2 c}{\partial x \partial t} - \{(\kappa_1 + \kappa_2^*)\beta + v + \lambda\beta\} \frac{\partial^2 c}{\partial t^2} - $$

$$v^2 \kappa_2^* \frac{\partial c}{\partial x} - \{(\kappa_1 + \kappa_2^*)(v + \lambda\beta) + \lambda v\} \frac{\partial c}{\partial t} - $$

$$(\kappa_1 + \kappa_2^*)\lambda v c = 0 \qquad (35)$$

where

$$\kappa_2^* = \kappa_2 + \lambda \qquad (36)$$

In order to be more concise we write (35) as

$$A \frac{\partial^3 c}{\partial x^2 \partial t} + B \frac{\partial^3 c}{\partial x \partial t^2} + C \frac{\partial^3 c}{\partial t^3} + $$

$$D \frac{\partial^2 c}{\partial x^2} + E \frac{\partial^2 c}{\partial x \partial t} + F \frac{\partial^2 c}{\partial t^2} + $$

$$G \frac{\partial c}{\partial x} + H \frac{\partial c}{\partial t} + I c = 0 \qquad (37)$$

The meaning of A through I should be immediately clear from a comparison of (37) with (35). Applying the theory of the last section we arrive at the following expressions for M_0, M_1, M_2^c, and M_3^c:

$$M_0 = e^{\gamma x} \qquad (38)$$

where

$$\gamma = \frac{-G - \sqrt{G^2 - 4DI}}{2D} \qquad (39)$$

$$M_1 = \frac{A\gamma^2 + E\gamma + H}{2\gamma D + G} x \qquad (40)$$

$$M_2^c = \frac{-2D(\frac{dM_1}{dx})^2 + (4A\gamma + 2E)\frac{dM_1}{dx} - 2B\gamma - 2F}{2\gamma D + G} x \qquad (41)$$

$$M_3^c = \frac{6A[\gamma \frac{dM_2^c}{dx} + (\frac{dM_1}{dx})^2] - 6B \frac{dM_1}{dx}}{2\gamma D + G} x$$
$$+ \frac{6C - 6D\frac{dM_2^c}{dx}\frac{dM_1}{dx} + 3E\frac{dM_2^c}{dx}}{2\gamma D + G} x \qquad (42)$$

Certain precautions have to be taken when programming the above formulas: Equation (39) fails if D – 0. In that case, use the alternative

$$\gamma = -\frac{I}{G} \qquad (43)$$

This one breaks down, however, if (besides D – 0) also G – 0. For that special case one has

$$\gamma = \frac{-E - \sqrt{E^2 - 4AH}}{2A} \qquad (44)$$

In the latter case (i.e. both D – 0 and G – 0) equations (40), (41) and (42) have to be replaced by

$$M_1 = \frac{\gamma B + F}{2A\gamma + E} x \qquad (45)$$

$$M_2^c = \frac{-2A(\frac{dM_1}{dx})^2 + 2B\frac{dM_1}{dx} - 2C}{2A\gamma + E} x \qquad (46)$$

$$M_3^c = \frac{3B\frac{dM_2^c}{dx} - 6A\frac{dM_2^c}{dx}\frac{dM_1}{dx}}{2A\gamma + E} x \qquad (47)$$

Finally, evaluation of (44) will be obstructed by A – 0, in which case (i.e. D – 0, G – 0, A – 0) the following applies

$$\gamma = -\frac{H}{E} \qquad (48)$$
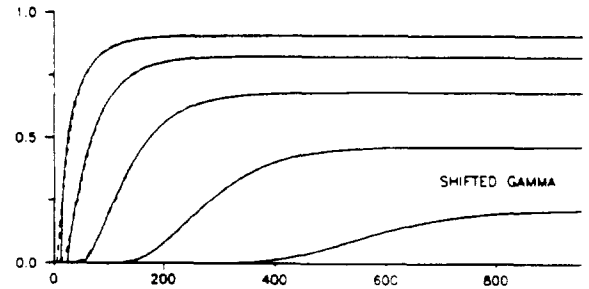
Fig. 11: Breakthrough curves by the shifted incomplete Gamma function, checked against an exact solution of Strack's differential equation, inclusive of decay and rate limited sorption. Vertical axis: dimensionless concentration. Horizontal axis: time in days. Breakthrough distances shown are x – 2, 4, 8, 16 and 32 m. Other parameter values: v – .1 m/d, α_L – 1 m, κ_1 – 1 d^{-1}, v – .0025 d^{-1}, κ_2 – 1 d^{-1}.

7

There are no further obstacles, except for our finding that M_2^c or M_c^3 may become - 0 (instead of + 0), due to numerical round off. (This becomes a problem only when calculating the parameters of the shifted incomplete Gamma-function). One can avoid this pitfall by setting a lower bound to M_2^c and M_c^3, equal to the smallest positive number. We have not attempted to solve (35) exactly, but a special case was found to occur if $\kappa_2^* = 1/\beta$, which could be solved by Laplace transformation. The above formulas were compared with this solution, of which Figure 11 gives a typical example.

Non-uniform flow

It can be shown that equation (35) remains unaltered if x is chosen along a (presumably) curvilinear stream line in a non-uniform flow field. The method outlined in the preceding section remains basically unaltered, too, but the second derivatives of the moments vanish no longer. The expressions found for the various moments are not accurate, if applied to non-uniform flow. We expect them not to be far off, however, be-cause the second derivatives of the various moments fluctuate around zero (going along an alternatingly converging and diverging flow path) while the moments themselves increase more or less steadily. As an example we evaluated several break-through curves along the curvilinear flow line shown in Figure 12. This line almost hits a stagnation point, which is about the worst thing to happen to our method. Figure 13 displays approximative breakthrough curves against 'exact' solutions, evaluated by the method of characteristics [Fairbrother, 1992]. The curves are calculated at equidistant points along the stream line. The non-uniformity of the flow field shows clearly from the uneven spacing in time of the curves, as the point of stagnation is being passed.

Exact solutions of M_0 through M_3^c are still possible in the non-uniform flow case, but the expressions become prohibitively involved and they contain integrals of the
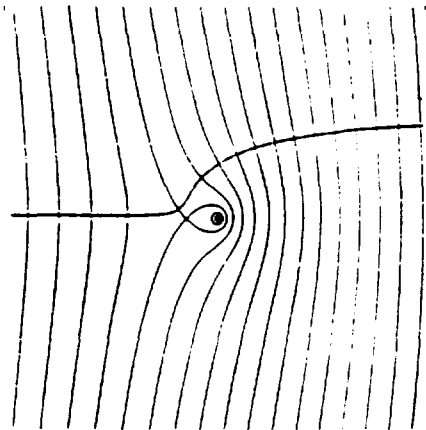
Figure 12: Non-uniform flow field (courtesy M.D Fairbrother. Univ of Minn.)
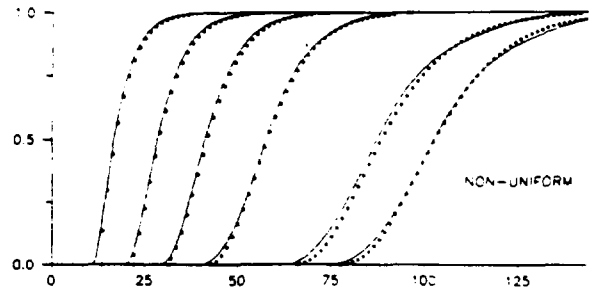
Figure 13: Some 'true' breakthrough curves along the curvilinear flow line shown in Figure 12, obtained by the method of characteristics (dotted, courtesy M.D. Fairbrother, Un. of Minn.) approximated by the shifted incomplete Gamma function (solid). Use was made of (44) through (47), with local values of M_1, M_2^c and M_3^c.

inverse of the velocity, which would have to be evaluated numerically anyway. As the travel time of a particle is already computed numerically in most groundwater models that are able to track flow lines, we recommend to do the same with the various moments. The equations to be integrated are

$$D\frac{d^2M_0}{dx^2} + G\frac{dM_0}{dx} + IM_0 = 0 \tag{49}$$

$$D\frac{d^2M_1}{dx^2} + (2M_0'D + G)\frac{dM_1}{dx} = A M_0'' + E M_0' + H \tag{50}$$

$$D\frac{d^2M_2^c}{dx^2} + (2DM_0' + G)\frac{dM_2^c}{dx} = (4AM_0' + 2E)M_1' - 2D(M_1')^2 - 2BM_0' - 2F \tag{51}$$

$$D\frac{d^2M_3^c}{dx^2} + (2M_0'D + G)\frac{dM_3^c}{dx} = 6A[M_0'(M_2^c)' + (M_1')^2] - 6BM_1' + 6C - 6D(M_2^c)' M_1' + 3E(M_2^c)' \tag{52}$$

Accents and double accents denote differentiation with respect to x. (We adopted this notation to distinguish moments, whose values are known from the previous equations, from the particular moment to be solved). Notice that A through I, C excepted, depend on v, which is a function of x when the flow field is non-uniform. All parameters, except E and F, may be zero, depending on the physical application.

There exist various numerical schemes to integrate second order ordinary differential equations. Most of them rewrite the equation as a system of two first order equations, which is solved by a Runge-Kutta method or any of its alternatives. The reader is referred to [Press et al., 1992] for a concise overview and sample routines. In applying these routines we are confronted with the neces-

sity to assign values to the first order derivatives of M_1, M_2^c and M_3^c at $x = 0$, which can be decently chosen equal to zero.

ACKNOWLEDGEMENTS

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APPENDIX

Moments and Cumulants

We remind the reader that the nth *moment* of an impulse response function $\theta(t)$ is defined by

$$M_n = \frac{\int_0^\infty t^n \theta(t) dt}{\int_0^\infty \theta(t) dt} \qquad (n > 0) \qquad (53)$$

The denominator equals the area A of the impulse response, also called M_0 in this paper. M_1 is the mean of $\theta(t)$, frequently denoted by μ. (One may notice that the moments, defined in this way, are 'normalized' moments in the sense of Section 2.2. M_0 has not been normalized, however). Higher order moments are often 'centralized' with respect to M_1, according to

$$M_n^c = \frac{\int_0^\infty t^n \theta(t-M_1) dt}{\int_0^\infty \theta(t) dt} \qquad (n > 0) \qquad (54)$$

M_2^c is the variance of $\theta(t)$, also denoted by σ^2. Employing the binomial expansion it follows that

$$M_n = M_n^c + \binom{n}{1}M_{n-1}^c M_1 + \binom{n}{2}M_{n-2}^c M_1^2 + ...$$
$$... + \binom{n}{n-2}M_2^c M_1^{n-2} + \binom{n}{n-1}M_1^c M_1^{n-1} + M_1^n \qquad (55)$$

(Notice that the second last term has got to vanish, because M_1^c is zero). As an alternative to (53) the nth moment is also defined as the coefficient of $(i\omega)^n/n!$ in the Taylor series of the Fourier transform of $\theta(t)$, which can be shown to be the same thing. (Here, ω is the Fourier transform variable). *Cumulants* are defined similar to moments, the difference being that the logarithm of the Taylor series is taken, rather than the Taylor series itself. From this one may derive the following formal relation between moments and cumulants:

$$\frac{M_n}{n!} = \sum_{i=1}^{n} \frac{i}{n} \frac{M_{n-i}}{(n-i)!} \frac{K_i}{i!} \qquad (56)$$

or, inversely,

$$\frac{K_n}{n!} = \frac{M_n}{n!} - \sum_{i=1}^{n-1} \frac{i}{n} \frac{M_{n-i}}{(n-i)!} \frac{K_i}{i!} \qquad (57)$$

Unlike moments there exist no 'central' cumulants: cumulants are invariant under centralization, except for K_1, which vanishes then. Thus, *central* moments are calculated from cumulants by

$$\frac{M_n^c}{n!} = \sum_{i=2}^{n} \frac{i}{n} \frac{M_{n-i}^c}{(n-i)!} \frac{K_i}{i!} \qquad (58)$$

A Note on Strack's Equation (33), (34)

The formulation of (33), (34) is sufficiently general to allow for various physical interpretations. In case of sorption on grains, for instance, the usual notation of (34) reads

$$\frac{\partial s}{\partial t} = \kappa(\kappa_d c - s) - \lambda s \qquad (59)$$

where s is the quantity of mass sorbed on the grains and κ_d is the *distribution coefficient,* or *partition coefficient,* of the Freundlich isotherm [*Domenico and Schwartz,* 1991], p441; Freeze and Cherry [1979], p403). In this case, c_s would have to be defined by

$$c_s = \frac{\rho}{\eta} s \qquad (60)$$

where ρ is the mass density of the grains and η is the porosity of the medium. The parameter κ in (59) determines the exchange rate of contaminant between sorbent and solute. Consequently, one would get

$$\kappa_1 = \frac{\rho}{\eta} \kappa \kappa_d \qquad (61)$$

$$\kappa_2 = \kappa \qquad (62)$$

On a quite different scale one might distinguish immobile zones within a heterogeneous porous medium, that are apt to penetration by contaminants through a diffusion-like process [*Coates and Smith,* 1964, *Herr et al.* 1988]. In that case s will be the concentration (mass/porosity) in the immobile phase, and

$$c_s = \frac{\eta_{im}}{\eta_m} s \qquad (63)$$

where η_{im} and η_m are the porosities of the immobile and mobile zones, respectively. Equation (34) would then read

$$\frac{\partial s}{\partial t} = \kappa(c - s) - \lambda s \qquad (64)$$

and thus

$$\kappa_1 = \frac{\eta_{im}}{\eta_m} \kappa \qquad (65)$$

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Appendix 5-E

Natural Attenuation Analysis

Appendix 5-E
Natural Attenuation Analysis

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Figure 5-E-30 Estimated Progression of Natural Attenuation

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Attachment 1 Natural Attenuation of Phenols in the WMGCP Aquifer

Appendix 5-E
Natural Attenuation Analysis

1.0 Overview

The following analysis demonstrates that natural attenuation is a site-wide process which progressively reduces contaminant concentrations in the sand aquifer at the WCP site, and progressively reduces mass loading to the surface water. This analysis extends and refines some of the modeling of Appendix 5-D. This modeling accounts for the downward movement of the upper fringe of the high concentration zone at the base of the aquifer (presented in Appendix 2-C). The Appendix 5-D modeling did not account for this effect, which is part of the conservatism of the Appendix 5-D work.

As explained in FS Section 2.3.2, the downward movement of the upper fringe of the high concentration zone at the base of the aquifer is a combination of hydraulic (groundwater flow) effects and biological activity effects. This appendix presents hydraulic effects, followed by an examination of biological activity effects. The presentation of hydraulic effects does not explicitly include modeling of biological activity, but does implicitly include biological activity effects, consistent with the time frames and effectiveness presented here for such biological activity.

The hydraulic analysis is appropriate for a chemical like arsenic, which is not expected to be significantly affected by biological activity in this site groundwater. This analysis shows that a focused removal, as proposed in Alternative 3, is as effective as a wide-spread removal scheme in attaining groundwater standards.

This appendix concludes with an evaluation of the anticipated effects of biological activity. Phenol is used to represent organics in this analysis. This work shows that natural attenuation can be expected to operate site-wide, on a progressive time frame.

2.0 Groundwater Flow and Transport Modeling

Contaminant transport modeling was performed to evaluate the long-term hydrogeologic effects in terms of natural attenuation of ammonia, arsenic, and phenols. Fate and transport to Lake

Michigan and Waukegan harbor were evaluated for Alternative 1 (No Action), Alternative 2 (Containment), and Alternative 3 (Removal). Due to the technical impracticability of Alternative 4 (Aquifer Restoration), this alternative was not evaluated. In lieu of this latter alternative, an expanded version of Alternative 3 covering the entire length of transects was evaluated.

In evaluating the results of the following predictions, the limited capability of fate and transport models must be considered. Therefore, predicted concentration profiles beyond few years should be viewed as approximations, suitable for comparative analyses. Furthermore, as these transects' concentration profiles reach low levels, their time frames should be considered as relative, order-of-magnitude estimates.

The SLAEM groundwater model was used for determining the fate and transport effects of the alternatives. The refined WCP site groundwater model, which was developed as part of the remedial investigation and was refined for the FS, was used as the base model upon which scenario modeling was conducted. The refined WCP site groundwater model is described in Appendix 2-B.

The contaminant transport modeling was conducted using the program CONTRA. CONTRA utilizes the convolutional solution method (Maas, 1994). The program CONTRA employs an Eulerian contaminant transport approach where the velocity filed is derived from an analytically computed flow regime (Fairbrother, 1992; Strack and Fairbrother, 1997). CONTRA is a transport module that is well suited for use with an analytic element model such as SLAEM (Strack, 1987, 1989). CONTRA is capable of addressing advection, classical dispersion, moving front dispersion, classical retardation, rate-limited sorption, and first-order biological or radioactive decay. Detailed descriptions of the convolutional method used in CONTRA are in the attachment "Efficient Approximate Solutions to 1-D Dispersive Transport Equations" included with Appendix 5-D.

For this study's natural attenuation evaluations, CONTRA was used to model transport of arsenic, ammonia, and phenols to Lake Michigan and Waukegan Harbor. Representative transects were chosen for each of the alternatives. Figure 5-E-1 shows the various transects corresponding to both harbor and lake pathways for each of the alternatives.

The modeling was used to develop "monitored concentrations" along both harbor and lake transects for increasing times in the future. These concentration profiles along harbor and lake transects are used to evaluate the natural attention of arsenic, ammonia, and phenols in groundwater. Monitored concentrations reflect the incorporation of an assumed well screening (i.e., sampling)

interval of 5 feet at the base of the aquifer. All deep aquifer monitoring wells presently installed on site have a 5-foot screen interval located directly above the till unit.

As described in Chapter 2 and Appendix 2-C, the downward movement of the upper fringe of the high concentration zone at the base of the aquifer has been occurring at least since the end of plant operations. This Appendix 5-E modeling of groundwater flow and transport incorporates that effect in estimating the "monitored" concentrations along the transects to the lake and the harbor.

As is typical of any groundwater transport modeling, several assumptions were made. Some are inherent in the modeling method and some are necessary in order to define model parameters. Refer to Appendix 5-D for a list of modeling assumptions.

2.1   Alternative 1 (No Action)

Modeling a No Action natural attenuation case provides a baseline against which to compare predicted concentrations of arsenic, ammonia, and total phenols along representative groundwater flow transects for the other remedial alternatives.

Groundwater travel to both harbor and lake originates near the groundwater divide which is located near the east side of the site. Figure 5-E-2 shows the location of the harbor and lake transects which are representative of typical flow patterns to both harbor and lake. Predicted concentrations are presented in following figures that represent natural attenuation behavior along each of these transects. The origin on Figures 5-E-3 through 5-E-8 represents the groundwater divide portion of each transect. Refer to section "Alternative 1 (No Action)" in Appendix 5-D for flow patterns, piezometric head distribution, and localized groundwater divides.

Figures 5-E-3 through 5-E-5 show concentration profiles along the harbor transect for arsenic, ammonia, and total phenols, respectively. Profiles are depicted on each figure corresponding to varying times into the future.

Figures 5-E-6 through 5-E-8 show concentration profiles along the lake transect for arsenic, ammonia, and phenols, respectively. Profiles are depicted on each figure corresponding to varying times into the future.

Because there is no groundwater treatment in this alternative, the concentrations from the groundwater divide propagate gradually toward the lake and harbor, and concentrations decline very gradually throughout the aquifer.

2.2   Alternative 2 (Containment)

Modeling a Containment natural attenuation case provides long-term predicted concentrations of arsenic, ammonia, and total phenols along representative groundwater flow transects.

Figure 5-E-9 shows the location of the harbor and lake transects which are representative of typical flow patterns to both harbor and lake. Predicted concentrations are presented in following figures that represent natural attenuation behavior along each of these transects. The origin on Figures 5-E-10 through 5-E-12 represents the west face of the containment cell for the harbor transect. Refer to section "Alternative 2 (Containment)" in Appendix 5-D for flow patterns, piezometric head distribution, localized groundwater divides, and modeled assumptions associated with this alternative.

Figures 5-E-10 through 5-E-12 show concentration profiles along the harbor transect for arsenic, ammonia, and total phenols, respectively. The transect is in a location unaffected by groundwater treatment. Profiles are depicted on each figure corresponding to varying times into the future illustrating the progress of natural attenuation after completion of the treatment cell groundwater remedy. The concentrations within the containment are not shown on these figures. Those concentrations are expected to remain essentially unchanged, at levels similar to the No Action case for the harbor-side.

The concentration profiles along the lake transect are presented below under Alternative 3 (Removal). The lake-side conditions for Alternatives 2 and 3 are very similar, so only the Alternative 3 modeling is considered to represent Alternative 2 lake-side conditions as well.

2.3   Alternative 3 (Removal)

Modeling a Removal natural attenuation case provides long-term predicted concentrations of arsenic, ammonia, and total phenols along representative groundwater flow transects.

Figure 5-E-13 shows the location of the harbor and lake transects which are representative of typical flow patterns to both harbor and lake receptors. Predicted concentrations are presented in

following figures that represent natural attenuation behavior along each of these transects. The origin on Figures 5-E-14 through 5-E-22 represents the groundwater divide portion of each transect. Refer to section "Alternative 3 (Removal)" in Appendix 5-D for flow patterns, piezometric head distribution, localized groundwater divides, and modeled assumptions associated with this alternative. This Appendix 5-E modeling used the 50 percent infiltration reduction case.

Figures 5-E-14 through 5-E-16 show concentration profiles along the harbor transect for arsenic, ammonia, and total phenols, respectively. The treatment cell operations are assumed to remove 85 percent of the arsenic, 50 percent of the ammonia, and 50 percent of the phenol from each cell. Higher ammonia removals may be achieved, which would somewhat accelerate the natural attenuation. Profiles are depicted on each figure corresponding to varying times into the future, illustrating the progress of natural attenuation after completion of the treatment cell groundwater remedy.

Figures 5-E-17 through 5-E-22 show concentration profiles along the lake transect for arsenic, ammonia, and total phenols. Profiles are depicted on each figure corresponding to varying times into the future. Figure 5-E-17 shows profiles over time for arsenic, assuming treatment cell operations remove 85 percent of the arsenic mass in the cells. This figure applies to both Alternative 3 (Removal) and Alternative 2 (Containment). As compared to No Action (Figure 5-E-6), the figure shows a significant effect on concentrations and a favorable effect on the time to reach very low concentrations.

Figures 5-E-18 and 5-E-19 show profiles over time for ammonia, assuming treatment cell operations remove 50 percent and 85 percent (respectively) of the ammonia mass in the cells. As compared to No Action (Figures 5-E-7), these figures both show significant effects on concentration and favorable effects on the time to reach very low concentrations. The Alternative 2 (Containment) remedy is modeled to achieve the Figure 5-E-19 condition. The Alternative 3 (Removal) remedy achieves the same condition if the above-ground treatment system achieves nominal efficiencies of 60 percent or greater ammonia removal. Lesser efficiencies would produce conditions closer to those represented on Figure 5-E-18.

Figures 5-E-20 and 5-E-21 show lake-side profiles over time for total phenols, assuming treatment cell operations remove 35 percent and 50 percent (respectively) of the phenol mass in the cells. As compared to No Action (Figure 5-E-8), these figures show increasing effects on concentrations and favorable effects on the time to reach very low concentrations. The Alternative 2 (Containment) remedy is modeled to achieve the Figure 5-E-20 condition. The Alternative 3 (Removal) remedy,

including the effects of nitrate reinjection, is modeled to achieve a condition intermediate to those shown on Figures 5-E-20 and 5-E-21.

2.4 Comparison of Treatment and Natural Attenuation for Attaining Groundwater Standards

2.4.1 Harbor-Side

In order to compare treatment with natural attenuation, Alternative 3 (Removal) was used as a baseline. A hypothetical case was created by applying treatment cells to all the groundwater on the harbor-side. The resultant concentration profiles for arsenic on the Alternative 3 harbor-side transect are shown in Figure 5-E-23. Comparing this figure to the Removal harbor-side arsenic figure, Figure 5-E-14, shows that concentrations over much of the harbor transect are lower for the early years under the hypothetical case. The comparison does not account for the time needed to implement treatment cells over the harbor-side; rather, the hypothetical case assumes instantaneous implementation. (Accounting for implementation time would substantially alter Figure 5-E-23, making it look much more like Figure 5-E-14).

To assess the relative time frames for achieving groundwater standards, a comparison was made between the Removal case and the hypothetical case arsenic concentrations over time along the harbor transect. The concentrations were tracked at a location outside the Removal groundwater treatment area, about halfway along the transect to the harbor. The plot of modeled concentration over time is shown in Figure 5-E-24. As that figure shows, the hypothetical case produces lower concentrations for about 30 years; then the concentrations are the same. If the time needed to implement treatment cells over the harbor-side were included, the difference in concentrations would be smaller during that time. Both cases are modeled to reach MCLs at about 90 years. This analysis illustrates that the attainment of groundwater standards for arsenic is not accelerated even by a very significant additional effort in groundwater treatment.

A parallel analysis was performed for ammonia. Figure 5-E-25 shows the harbor-side concentration profiles for ammonia, assuming 85 percent ammonia mass removal in the Alternative 3 configuration of cells. The hypothetical case of applying treatment cells to all the groundwater on the harbor-side is shown in Figure 5-E-26. A plot of modeled concentration over time, for a location about halfway along the transect to the harbor, is shown in Figure 5-E-27. The result is very similar to the result for arsenic. For the first 30 years, the modeled concentrations are higher for the Alternative 3 scenarios, but after that the hypothetical and Alternative 3 concentrations are the

same. As before, if the time needed to implement the hypothetical case were included, there would be much less difference between the hypothetical case and the Alternative 3. The analyses of arsenic and ammonia illustrate that attainment of low groundwater concentrations is not accelerated by the very significant additional effort that would be required to treat the entire harbor-side.

The analysis of natural attenuation for phenol is deferred to Section 3 of this appendix, as there are special intrinsic biodegradation considerations that need to be added to the analysis. Explicitly accounting for these special considerations is beyond the capabilities of the groundwater fate and transport model.

2.4.2 Lake-Side

The area of treatment cell application on the lake-side for Alternatives 3 (Removal) and 2 (Containment) covers practically the entire lake-side transect (see Figure 5-E-13 for the transect location). This is true for most lake-side transects in the area of elevated COC concentration. There is, consequently, little or no difference between the Alternative 3 (or Alternative 2) groundwater quality along the transect and the groundwater quality that would be produced by a hypothetical application of cells to the entire lake-side.

The transect time-series figures (Figures 5-E-14 through 5-E-21, for instance) show one way of viewing the progress toward low concentrations in the lower 5 feet of the aquifer. Another approach is shown in Figures 5-E-28 and 5-E-29. These figures present the modeled concentration of arsenic and ammonia, respectively, over time at a location a little less than half-way along the beach transect (near monitoring well W-13D). The modeling indicates that after completion of the groundwater treatment cell work, natural attenuation will cause the concentrations monitored in the first 5 feet above the till to progressively decline. The modeling indicates that attainment of MCLs for arsenic should progress somewhat more quickly on the lake-side than on the harbor-side (less than 50 years lake-side as opposed to nearly 90 years harbor-side). The modeling in this appendix does not account for growth of the beach, which would tend to slow the natural attenuation processes, but would not alter the trends or general conclusions presented here.

3.0 Biological Activity Effects

Biological activity effects on natural attenuation of site groundwater after cell treatment was evaluated in order to develop an estimated time required for significant improvement in the water quality in the upper and lower portions of the aquifer. Cell treatment, presented in detail in Appendix 5-B, involves extraction of two to four pore volumes of groundwater from the interior of the treatment cells, above-ground treatment, and reinjection of the treated groundwater at the perimeter of the cells. The cell treatment is intended to significantly reduce the total mass of constituents of concern (COCs) in the cells and allow for further reductions in the concentrations and mass of COCs by biological activity and other natural attenuation mechanisms. The following paragraphs discuss the mechanisms involved with natural attenuation of organics, and also provide an estimated time frame for natural attenuation mechanisms to significantly reduce phenol mass and improve the site groundwater quality.

Examination of the 1997 beach transect data indicated the deep-groundwater phenols are being degraded as the groundwater travels toward Lake Michigan. However, activity appears to be inhibited at the base of the aquifer in the first 5 feet above the till aquitard. Evidence of activity is found in a plume "fringe" zone immediately above the inhibited zone. Depletion of phenols and sulfate in the fringe zone indicates that the phenols are being degraded by sulfate-reducing bacteria. The location of the sulfate-reducing activity suggests that there is a matrix effect associated with the COC concentrations in the deep groundwater which must be reduced to remove the inhibition and allow for biodegradation to occur. The Treatability Study to Evaluate Aerobic Bioremediation of Contaminated Site Groundwater (Fluor Daniel, 1998) and the beach transect data both show the matrix effect is alleviated as the groundwater concentrations are diluted.

In the treatability study, an aerobic environment, biodegradation of phenols was observed with dilution factors of as little as 2 to 3 (blending one part groundwater from immediately above the till one to two parts shallow groundwater). In the beach transect data, the environment at the upper fringe of the COC concentration zone is anaerobic, and biodegradation of phenols was observed at COC concentrations that represent dilution factors of 10 to 50. As was found in the treatability study, a combination of otherwise noninhibitory chemicals can produce a strong inhibitory effect. This was observed when phenol and thiocyanate. individually noninhibitory or only slightly inhibitory to ammonia degradation, were strongly inhibitory to ammonia degradation when both were present. Consequently, no single parameter was used to represent the matrix inhibition effect on biodegradation. Rather, the matrix effect was assumed to be fully alleviated as fresh infiltrated

water displaced the COC concentration zone water. The treatability study data and the beach transect data suggest that the strength of the matrix effect varies over a continuum of concentrations. The use of displacement by fresh infiltration is intended only as a credibly conservative approach to estimating the alleviation of matrix inhibition on biodegradation under natural attenuation.

Hydraulic modeling, similar to that in Appendix 2-C, was performed to estimate the downward movement of the matrix effect over time. Transects were modeled for the harbor-side and lake-side, based on the Alternative 3a (50 percent infiltration reduction) case. The modeling showed the harbor-side groundwater improves more slowly than the lake-side groundwater, so the harbor-side time frames are used here to represent the expected natural attenuation progress. Figure 5-E-30 shows the estimated time frames for removal of the inhibitory matrix effect based on the groundwater modeling. This process is effective over the entire extent of COC distribution. The upper fringe of the COC concentration zone moves downward progressively, so that over the course of 10 years, the upper one-third of the remaining COC concentration zone discharging to the harbor becomes available for biodegradation of organics. During the next 15 years, another one-third of the COC concentration zone becomes available for biodegradation. By 50 years, the discharge of COCs to the harbor and lake will have been substantially eliminated, and natural attenuation processes will gradually remove the remaining COC concentrations at the base of the aquifer.

Figure 5-E-30 illustrates in cross section the zones and time frames for conditions to become favorable for biodegradation processes. The data from the site strongly indicate that natural attenuation will progress in these zones as the matrix effect is alleviated.

To evaluate the likely biodegradation in these zones, a one-dimensional transport model was developed along a lake-side and a harbor-side flow path transect. A description and discussion of this biodegradation model is included as Attachment 1. The biodegradation mechanisms included in the model are phenol degradation by sulfate-reducing bacteria and by methane-producing bacteria. Aerobic activity is unlikely because of the many opportunities for oxygen to be consumed prior to penetrating to the base of the aquifer. The results of the biodegradation model show that phenol degradation occurred rapidly once the matrix effect inhibition was removed. The time required to substantially degrade the phenols in any zone where the inhibition has been removed is estimated to be about three years. The results of the model also suggest that the upper zone of the aquifer, where the phenol concentration would be similar to reinjected water from the above-ground treatment system, would undergo significant natural attenuation and the phenol would likely be completely degraded prior to the discharge to the lake or harbor.

This analysis concludes that conditions favorable for natural attenuation processes should exist over the entire extent of COC concentrations. The natural attenuation processes will progressively work their way downward, and will reduce the COC concentrations within the deep portion of the sand aquifer and will also decrease the mass of COCs discharged to the lake and harbor. Based on this analysis, the mass loadings presented in Appendix 5-D are conservative over-estimates, becoming increasingly conservative with time. The combination of cell treatment and natural attenuation offers significant mass removal for the highest concentration areas and widespread progressive reductions in COC concentration zone thickness and mass flux.

References

Maas, C., 1994. On Convolutional Processes and Dispersive Groundwater Flow. Ph.D. Thesis, Delft University of Technology.

Fairbrother, M.D., 1992. Numerical Solution to the Hyperbolic Differential Equation for Moving Front Dispersion with Rate Limited Sorption and Decay: A Method of Characteristic Approach, Msc. Thesis, University of Minnesota, Graduate School.

Strack, O.D.L., 1987. The analytic element method for regional groundwater modeling. Proceedings of the Solving Groundwater Problems with Models Conference and Exposition, Vol. 2, Feb. 10–12, 1987, Colorado.

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Harbor-Side
Transects

Lake-Side
Transects

Alternative 1 (No Action)
Alternative 2 (Containment)
Alternative 3 (Removal)
Alternative 4 (Aquifer Restoration)

N

0   200   400   600   800 Feet

Barr Arcview 3.0a, c:\aem\si3\waukall\gis\wauk.apr, Layout, Layout5.mdf, Mon Oct 12 14.11.30 1998

Figure 5-E-1

HARBOR-SIDE AND LAKE-SIDE
TRANSECT LOCATIONS, ALTERNATIVES 1-4
Waukegan Manufactured Gas & Coke Plant Site

Barr. Arcview 3 0a, c:\aern\si3\waukalligs\wauk.apr, Layout: Layout5, mdf, Mon Oct 12 14:11:30 1998

Lake-Side
Transect

Harbor-Side
Transect

N

| 0 | 200 | 400 | 600 | 800 | Feet |
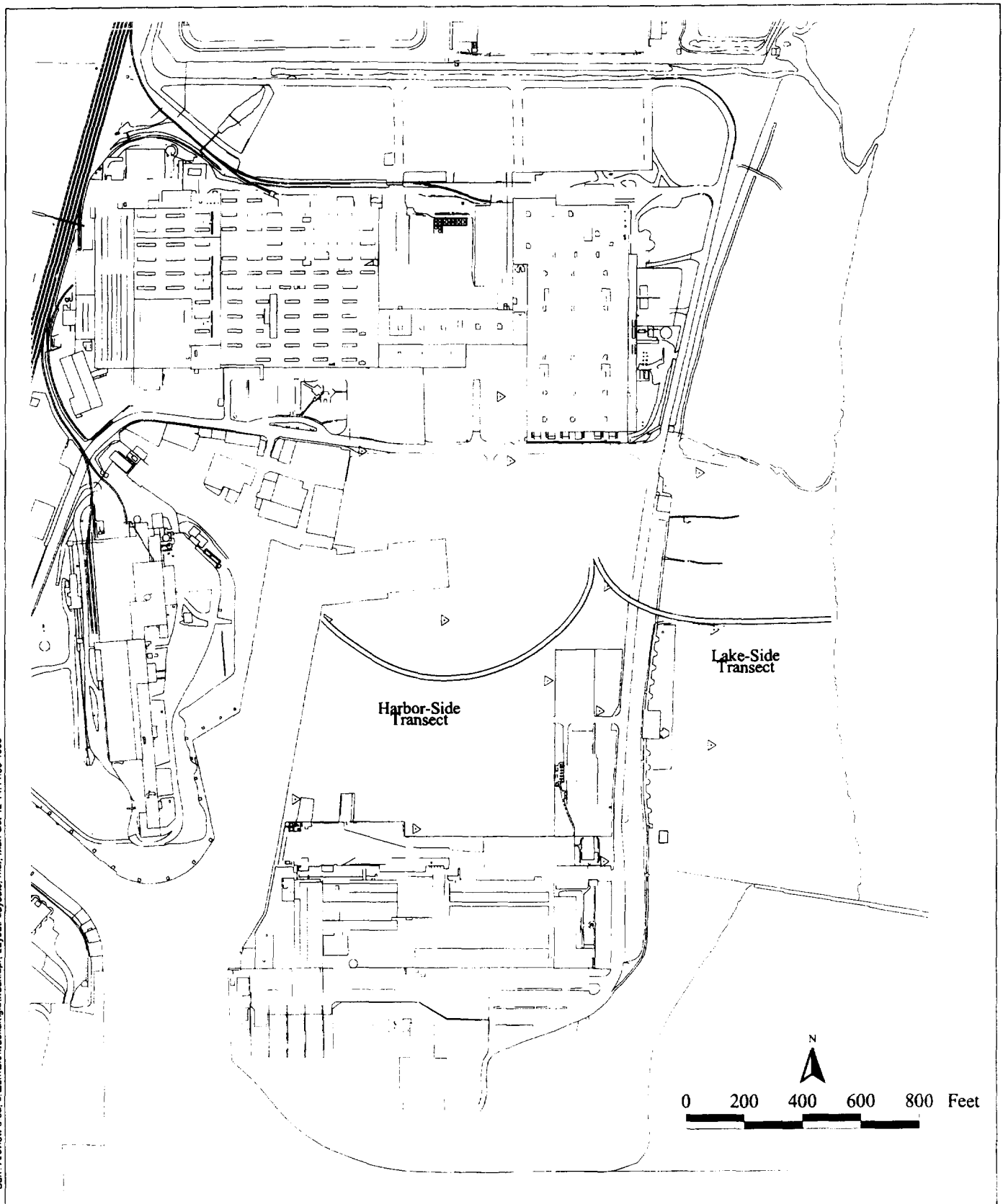
Figure 5-E-2

NO ACTION,
HARBOR-SIDE AND LAKE-SIDE
TRANSECT LOCATIONS
Waukegan Manufactured Gas & Coke Plant Site

Alternative 1: Harbor-Side Transect

Arsenic

Monitored Concentration [mg/L]

Distance Along Pathline [ft]

T = 5

T = 90

Time(yrs)=5,10,20,30,40,50,70,90

Alternative 1: Harbor-Side Transect
Ammonia

Time(yrs)=5,10,20,30,40,50,70,90
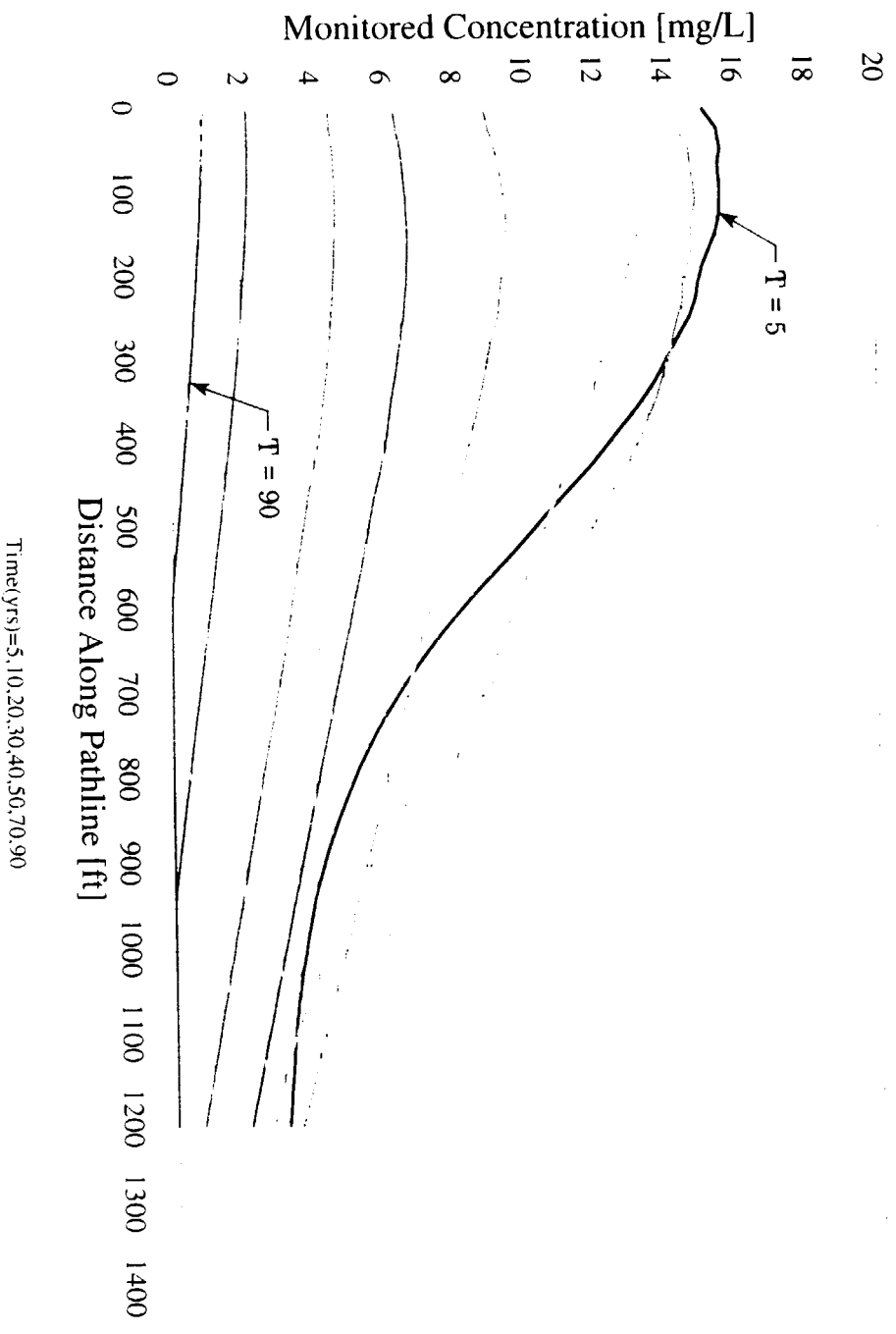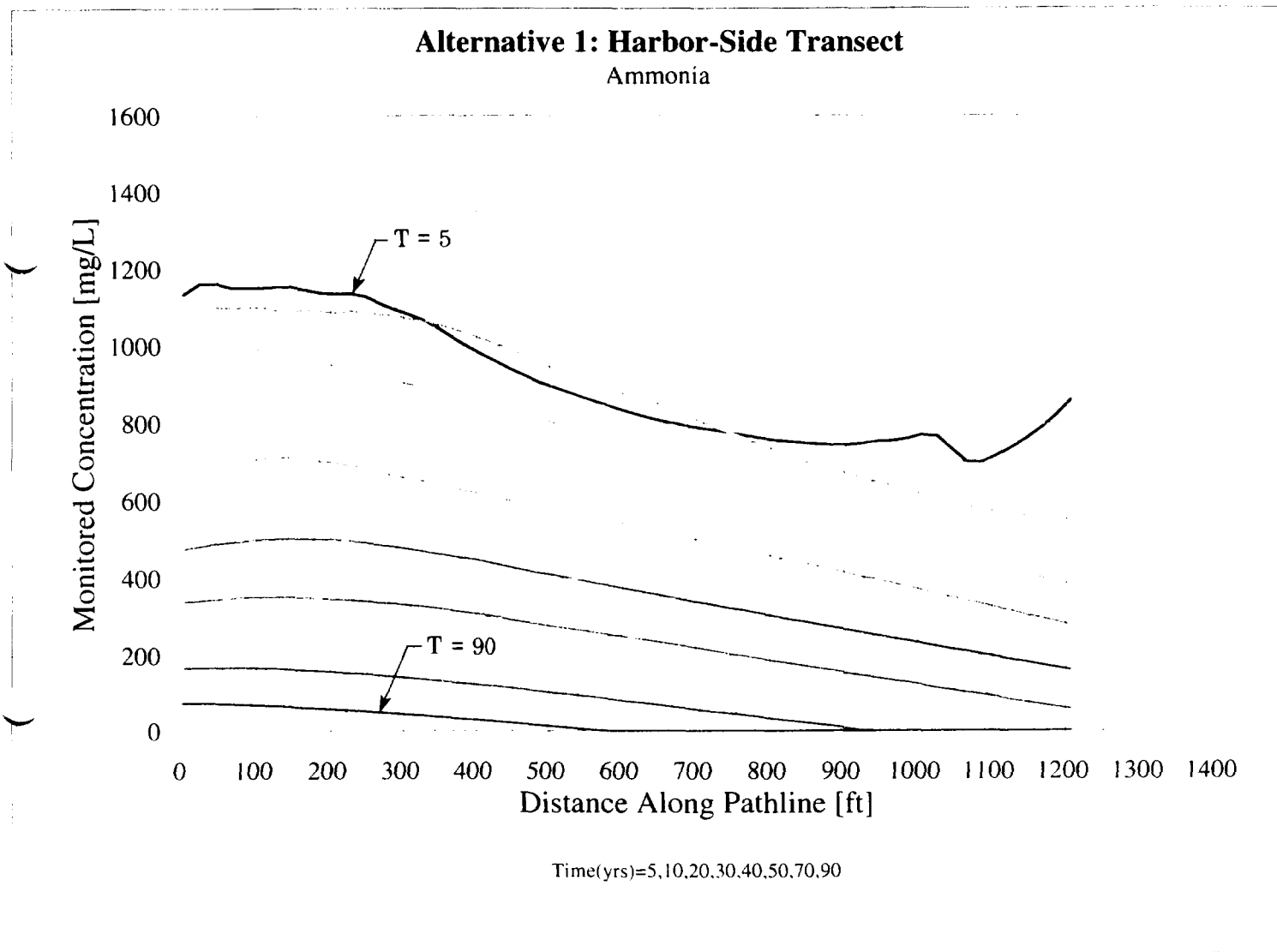
Figure 5-E-4
NO ACTION,
HARBOR-SIDE TRANSECT, AMMONIA
Waukegan Manufactured Gas & Coke Plant Site

Alternative 1: Harbor-Side Transect
Total Phenols

Time(yrs)=5,10,20,30,40,50,70,100
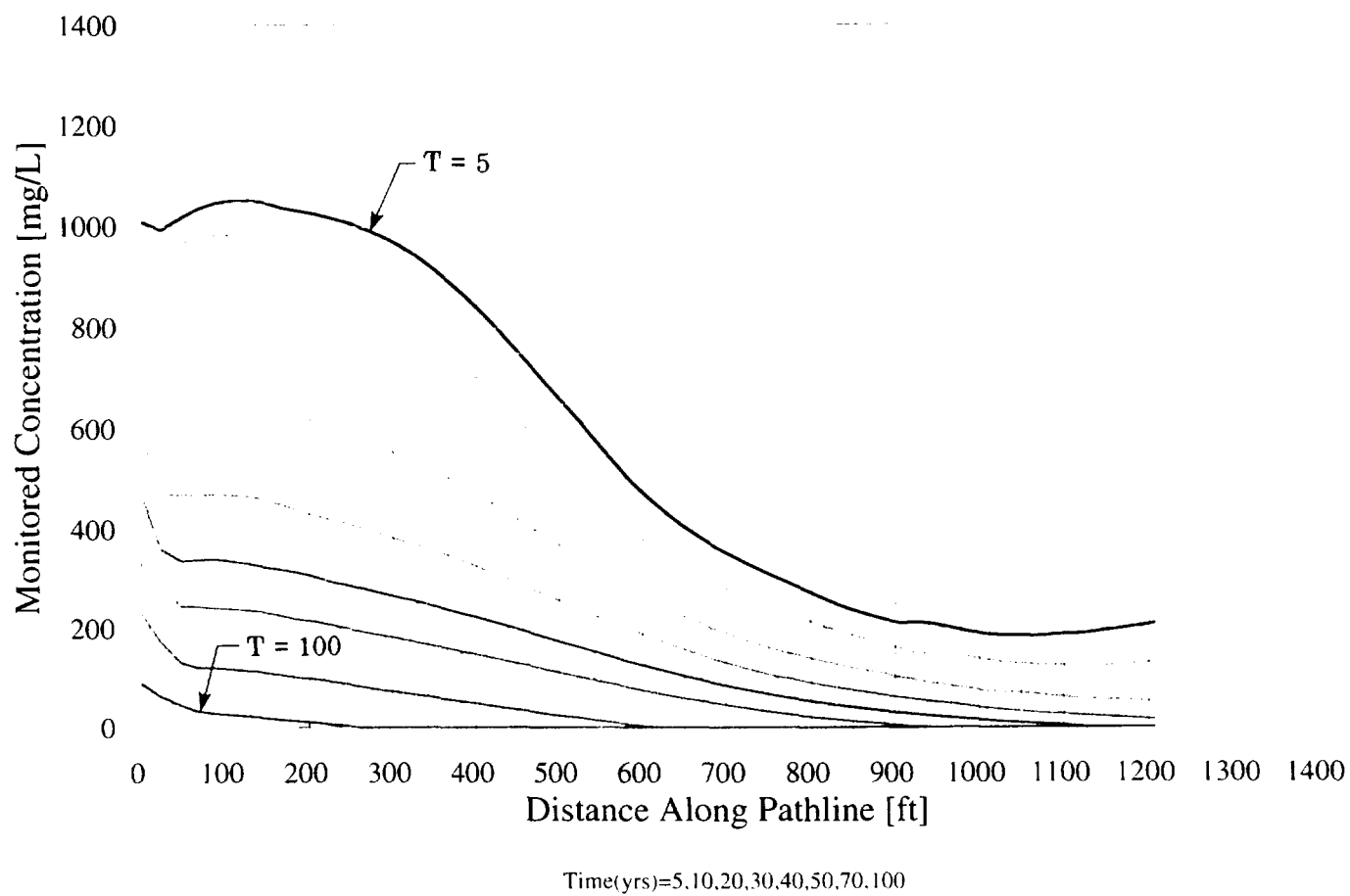
Figure 5-E-5

NO ACTION,
HARBOR-SIDE TRANSECT, TOTAL PHENOLS
Waukegan Manufactured Gas & Coke Plant Site

Alternative 1: Lake-Side Transect

Arsenic

Monitored Concentration [mg/L]

Distance Along Pathline [ft]

T = 5

T = 70

Time(yrs)=5,10,20,30,40,50,70
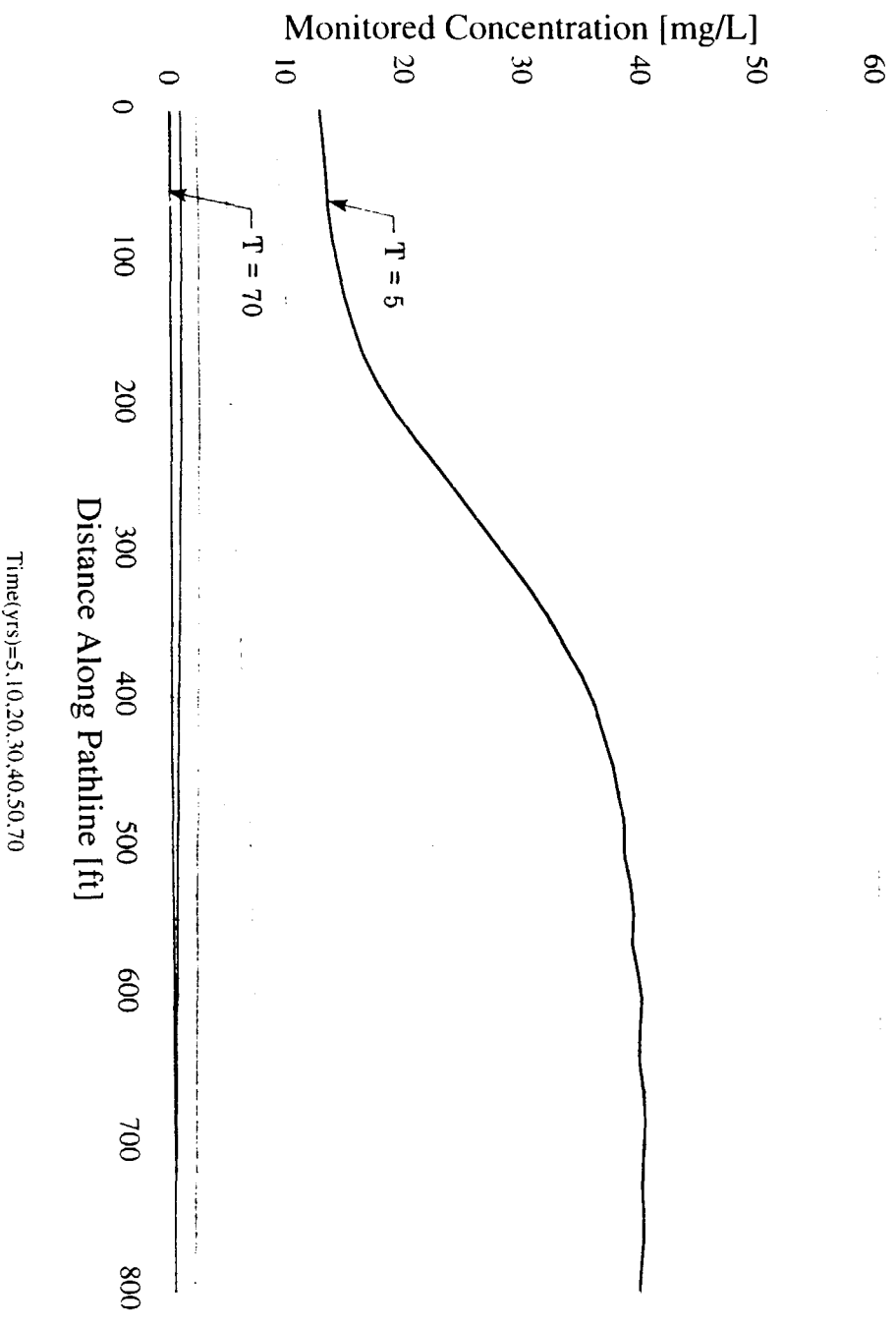
Figure 5-E-6
NO ACTION,
LAKE-SIDE TRANSECT, ARSENIC
Waukegan Manufactured Gas & Coke Plant Site

Alternative 1: Lake-Side Transect
Ammonia

Time(yrs)=5,10,20,30,40,50,70
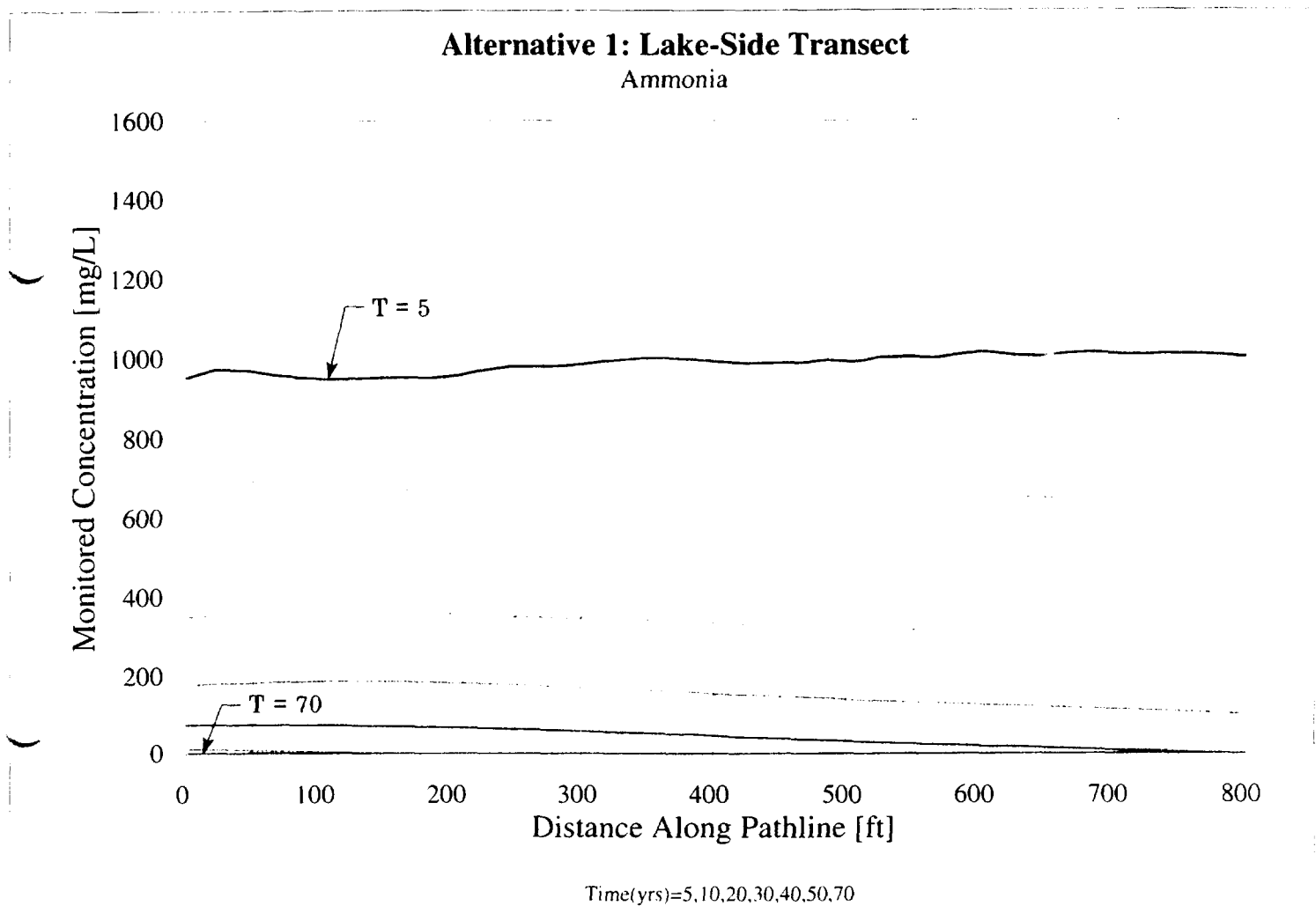
Figure 5-E-7

NO ACTION,
LAKE-SIDE TRANSECT, AMMONIA
Waukegan Manufactured Gas & Coke Plant Site

Alternative 1: Lake-Side Transect
Total Phenols

Time(yrs)=5,10,20,30,40,50,70,100

Harbor-Side
Transect

Lake-Side
Transect

Barr Arcview 3 0a, c:\aemus\3\waukal\tgis\wauk apr, Layout: Layout5, mdf, Mon Oct 12 14 11 30 1998

N

0   200   400   600   800 Feet

Figure 5-E-9

CONTAINMENT,
HARBOR-SIDE AND LAKE-SIDE
TRANSECT LOCATIONS
Waukegan Manufactured Gas & Coke Plant Site

Alternative 2: Harbor-Side Transect

Arsenic

Monitored Concentration [mg/L]

20
18
16
14
12
10
8
6
4
2
0

T = 5
T = 90

Distance Along Pathline [ft]

0   100   200   300   400   500   600   700   800   900   1000   1100   1200   1300   1400

Time(yrs)=5,10,20,30,40,50,70,90

Figure 5–E–10
CONTAINMENT,
HARBOR-SIDE TRANSECT, ARSENIC
Waukegan Manufactured Gas & Coke Plant Site

Alternative 2: Harbor-Side Transect
Ammonia

Time(yrs)=5,10,20,30,40,50,70,90
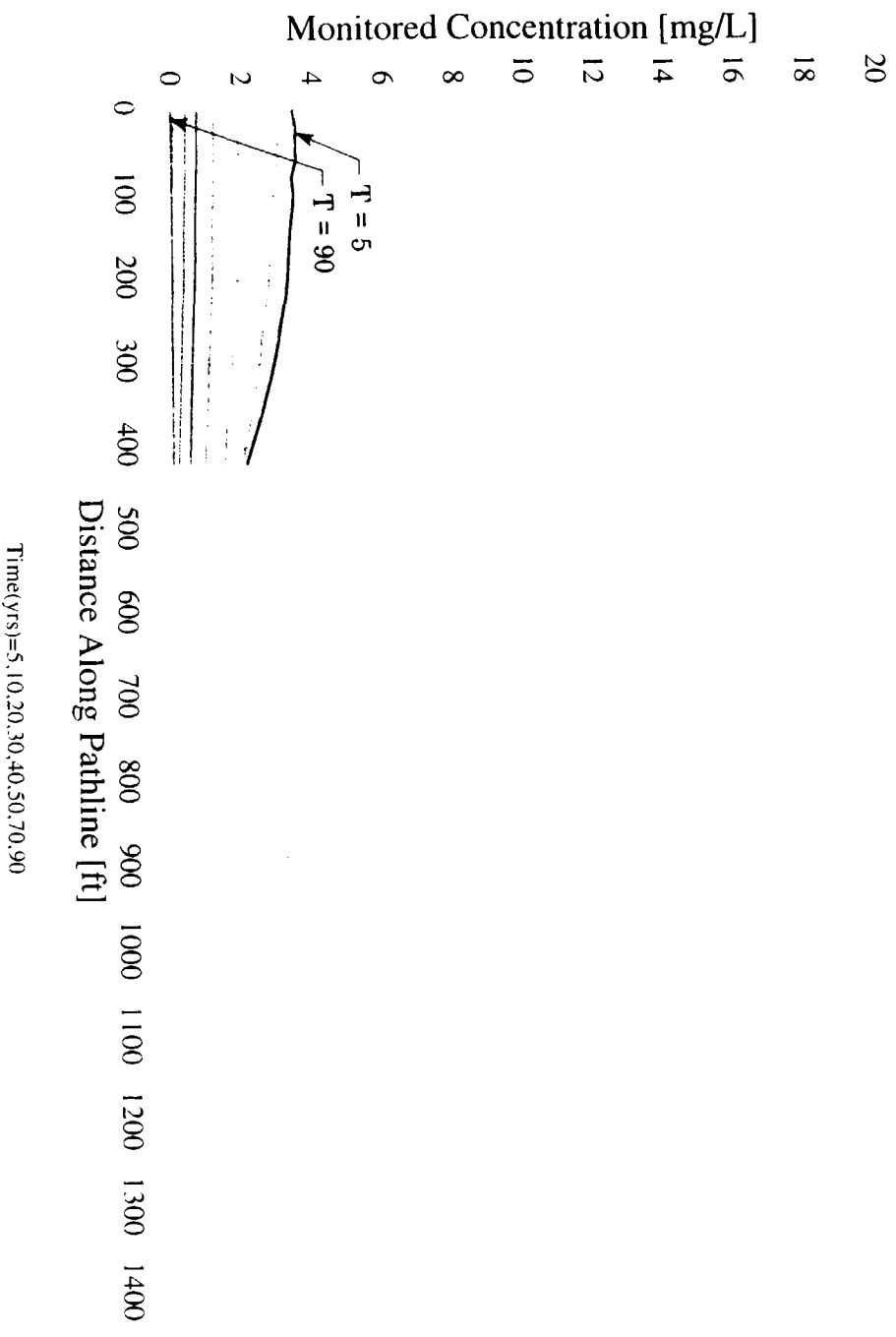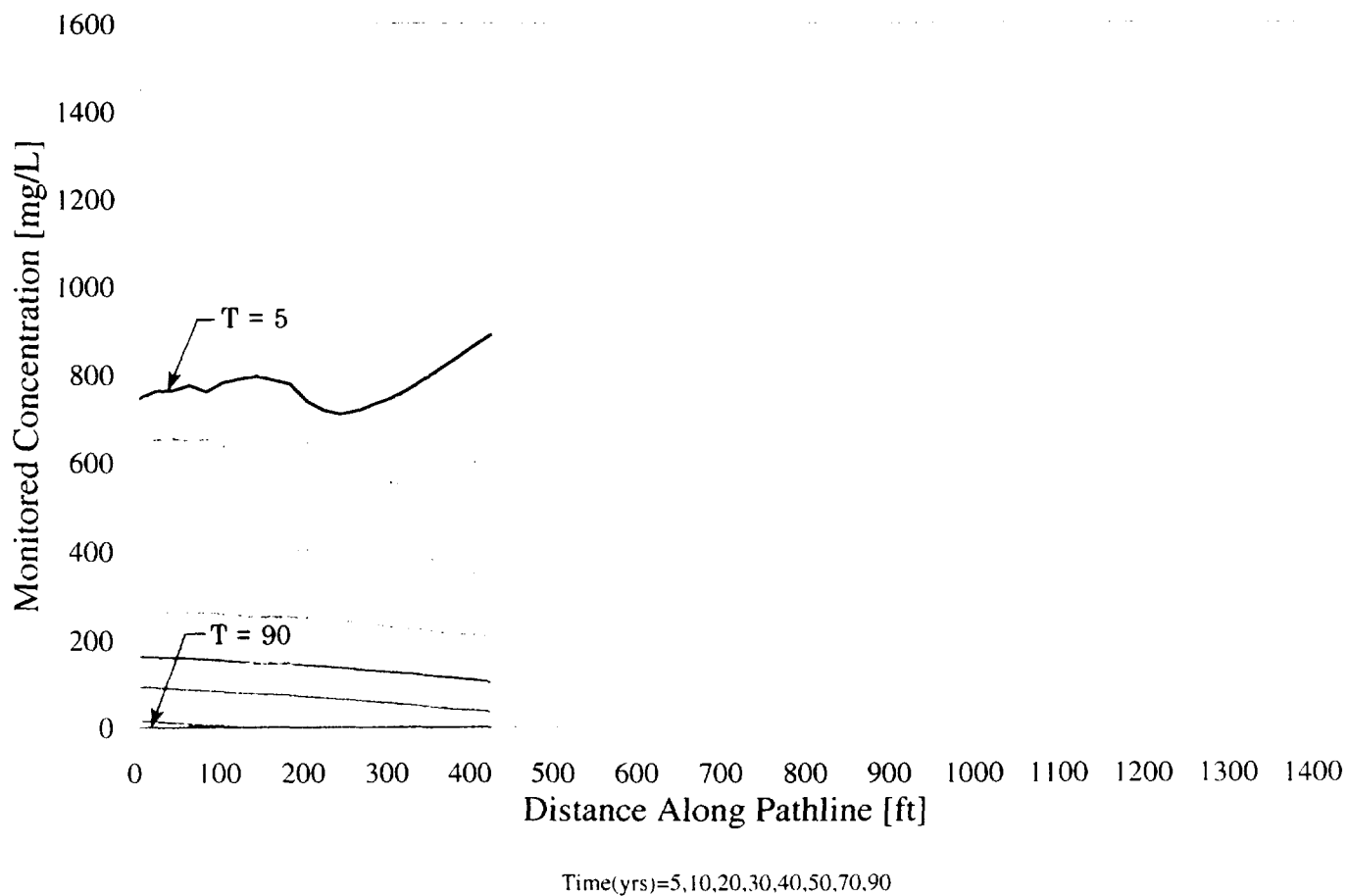
Figure 5-E-11
CONTAINMENT,
HARBOR-SIDE TRANSECT, AMMONIA
Waukegan Manufactured Gas & Coke Plant Site

Alternative 2: Harbor-Side Transect
Total Phenols

Figure 5-E-12

CONTAINMENT,
HARBOR-SIDE TRANSECT, TOTAL PHENOLS
Waukegan Manufactured Gas & Coke Plant Site

Lake-Side
Transect

Harbor-Side
Transect

Barr Arcview 3.0a, c:\aem\si3\waukati\gis\wauk.apr, Layout: Layout5, mdf, Mon Oct 12 14.11:30 1998

N

0   200   400   600   800   Feet
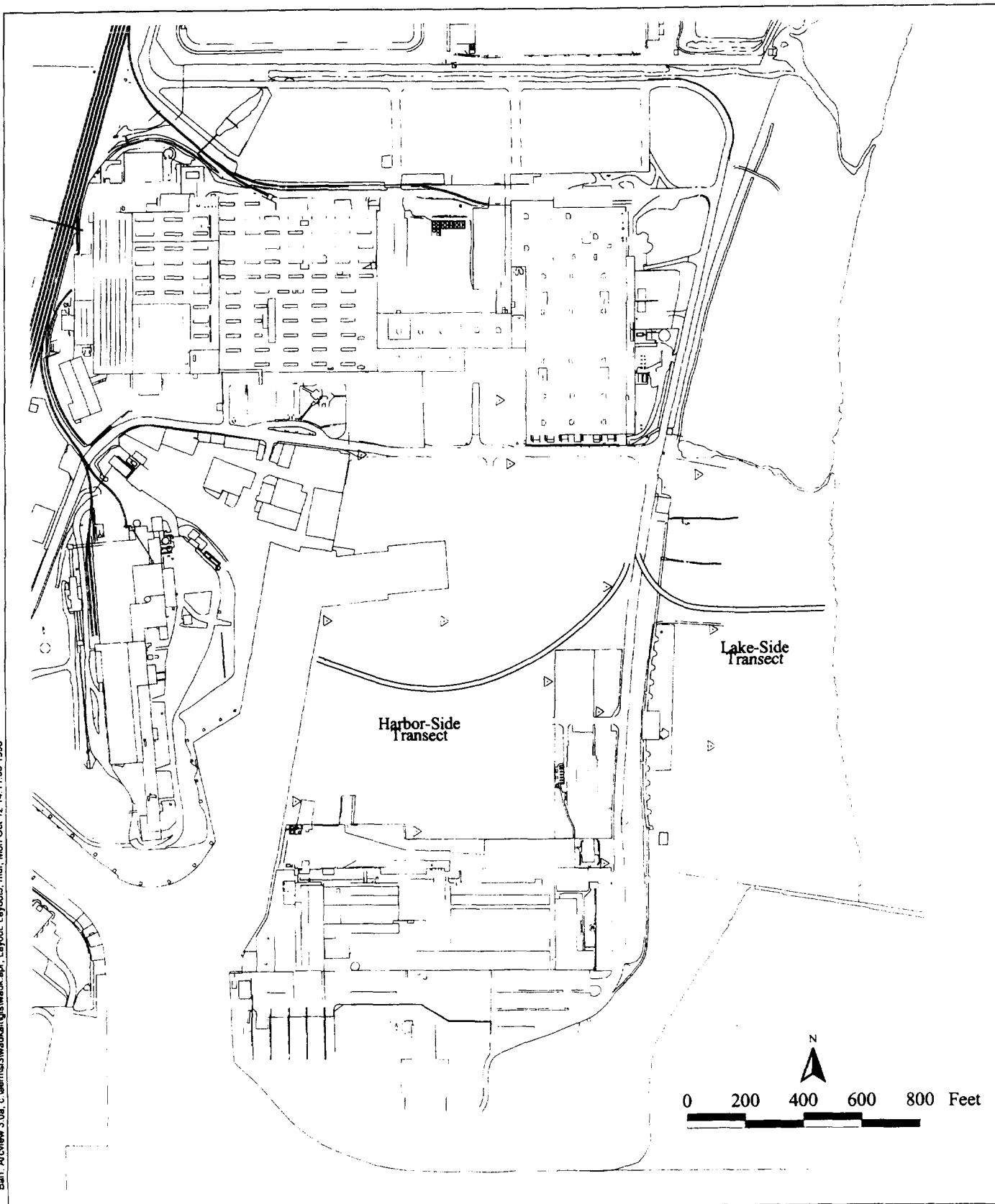
Figure 5-E-13

REMOVAL,
HARBOR-SIDE AND LAKE-SIDE
TRANSECT LOCATIONS
Waukegan Manufactured Gas & Coke Plant Site

Alternative 3: Harbor-Side Transect
Arsenic

Time(yrs)=5,10,20,30,40,50,70,90
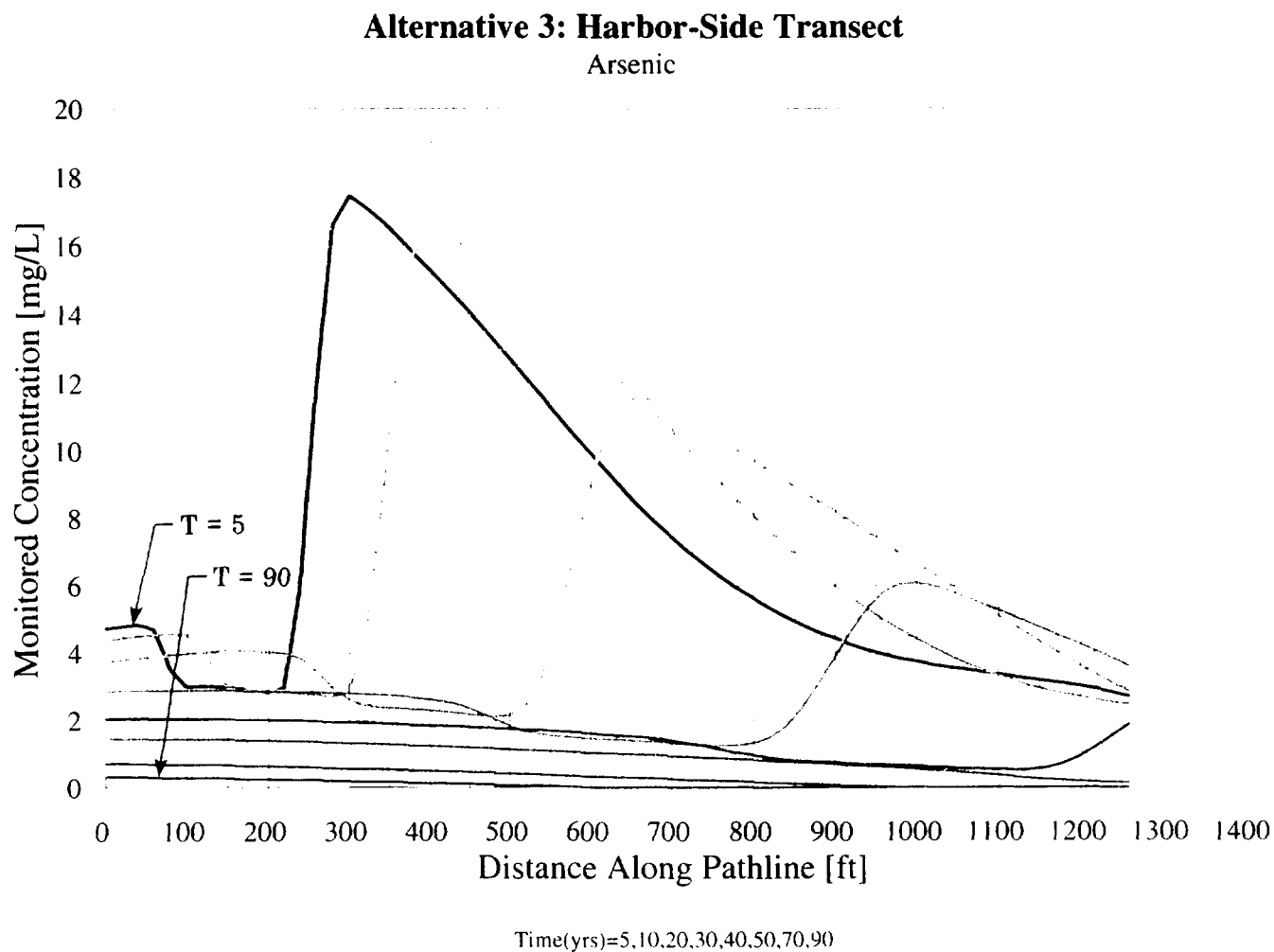
Figure 5-E-14

REMOVAL,
HARBOR-SIDE TRANSECT, ARSENIC
Waukegan Manufactured Gas & Coke Plant Site

Alternative 3: Harbor-Side Transect

Ammonia

Time(yrs)=5,10,20,30,40,50,70,90
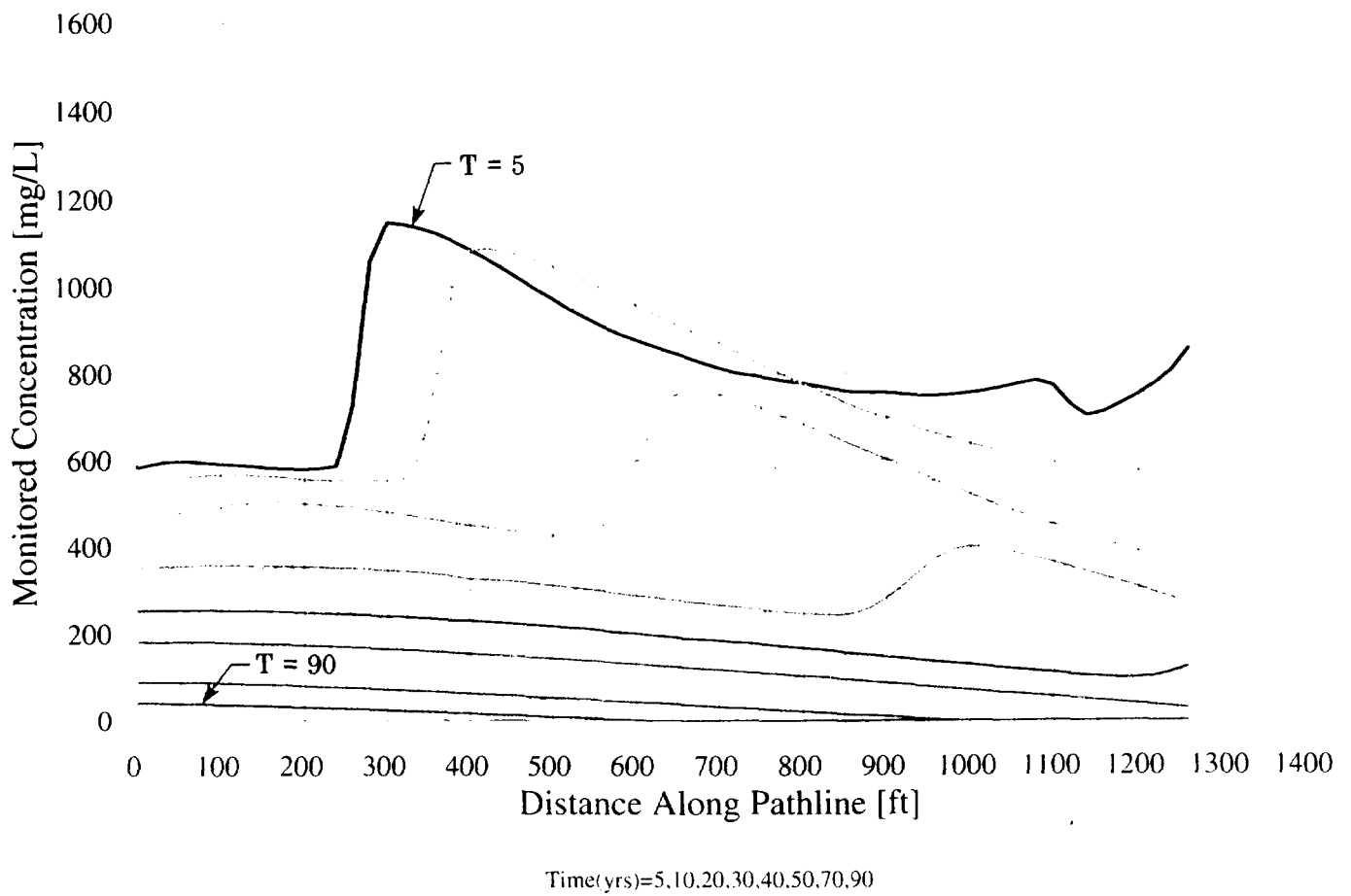
Figure 5-E-15

REMOVAL,
HARBOR-SIDE TRANSECT, AMMONIA
Waukegan Manufactured Gas & Coke Plant Site

Alternative 3: Harbor-Side Transect
Total Phenols

Monitored Concentration [mg/L]

T = 100

T = 5

Time(yrs)=5,10,20,30,40,50,70,100

Distance Along Pathline [ft]
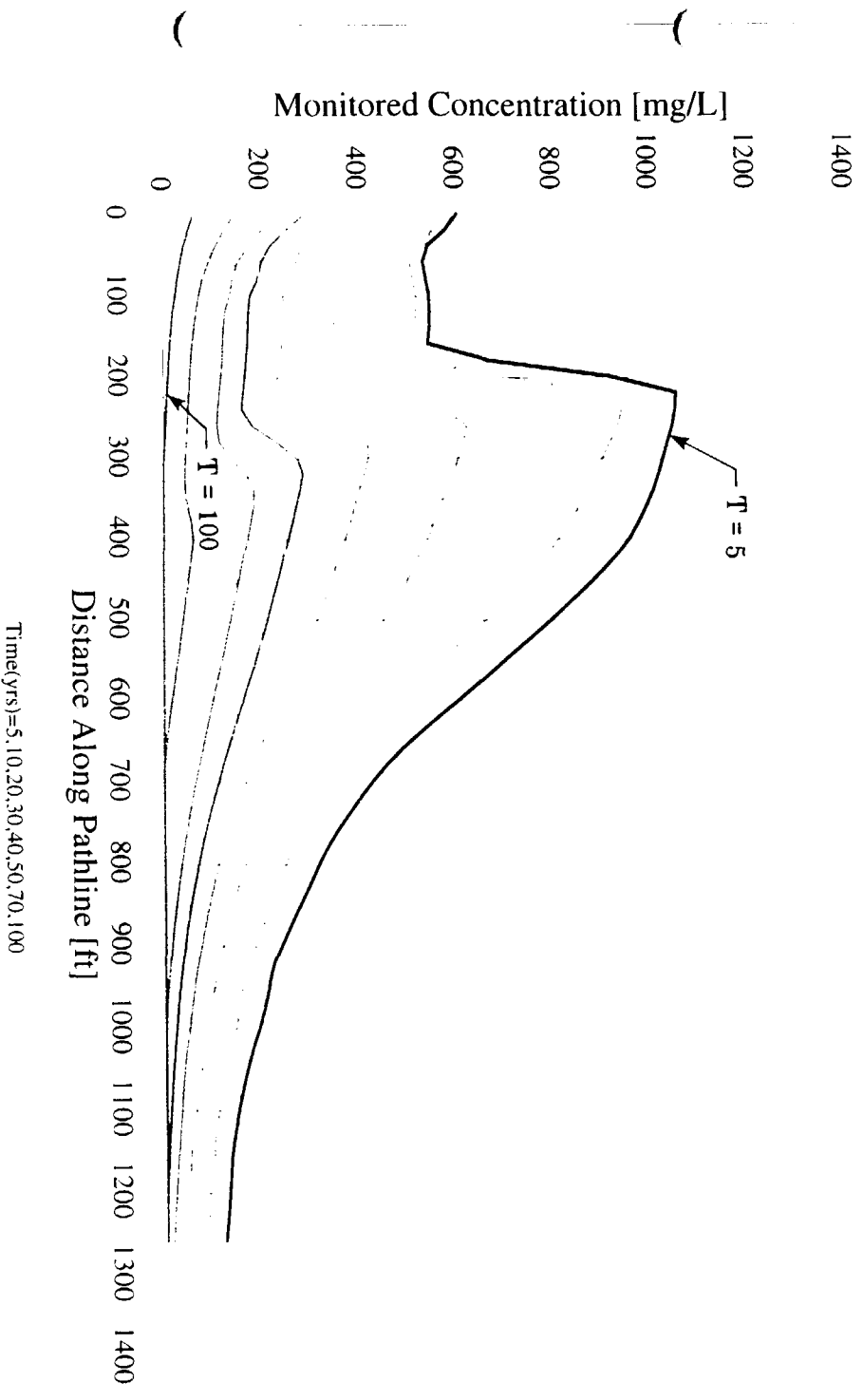
Figure 5-E-16
REMOVAL,
HARBOR-SIDE TRANSECT, TOTAL PHENOLS
Waukegan Manufactured Gas & Coke Plant Site

Alternative 3: Lake-Side Transect

Arsenic

Time(yrs)=5,10,20,30,40,50
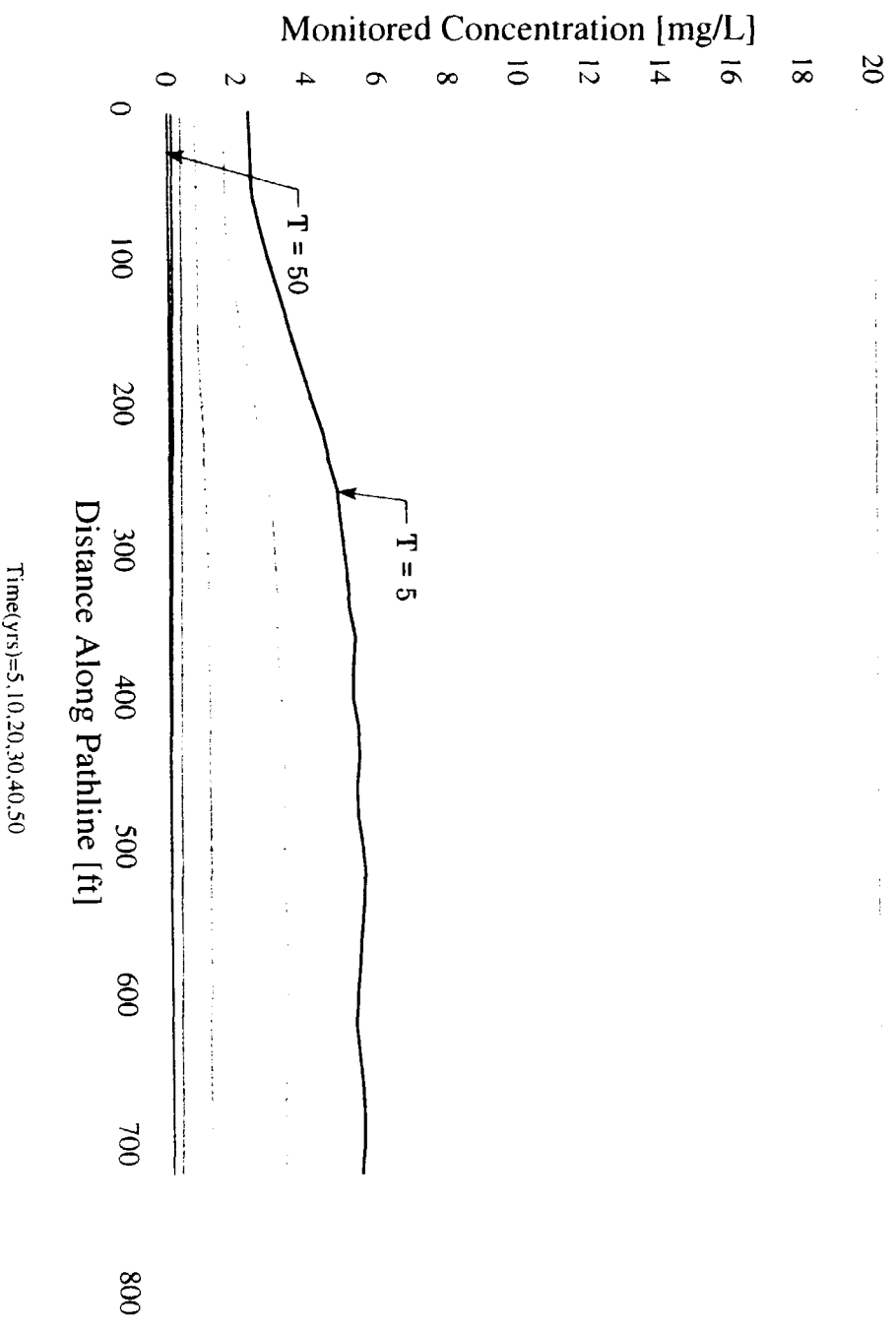
Figure 5-E-17
REMOVAL,
LAKE-SIDE TRANSECT, ARSENIC
Waukegan Manufactured Gas & Coke Plant Site

Alternative 3: Lake-Side Transect
Ammonia

Time(yrs)=5,10,20,30,40,50
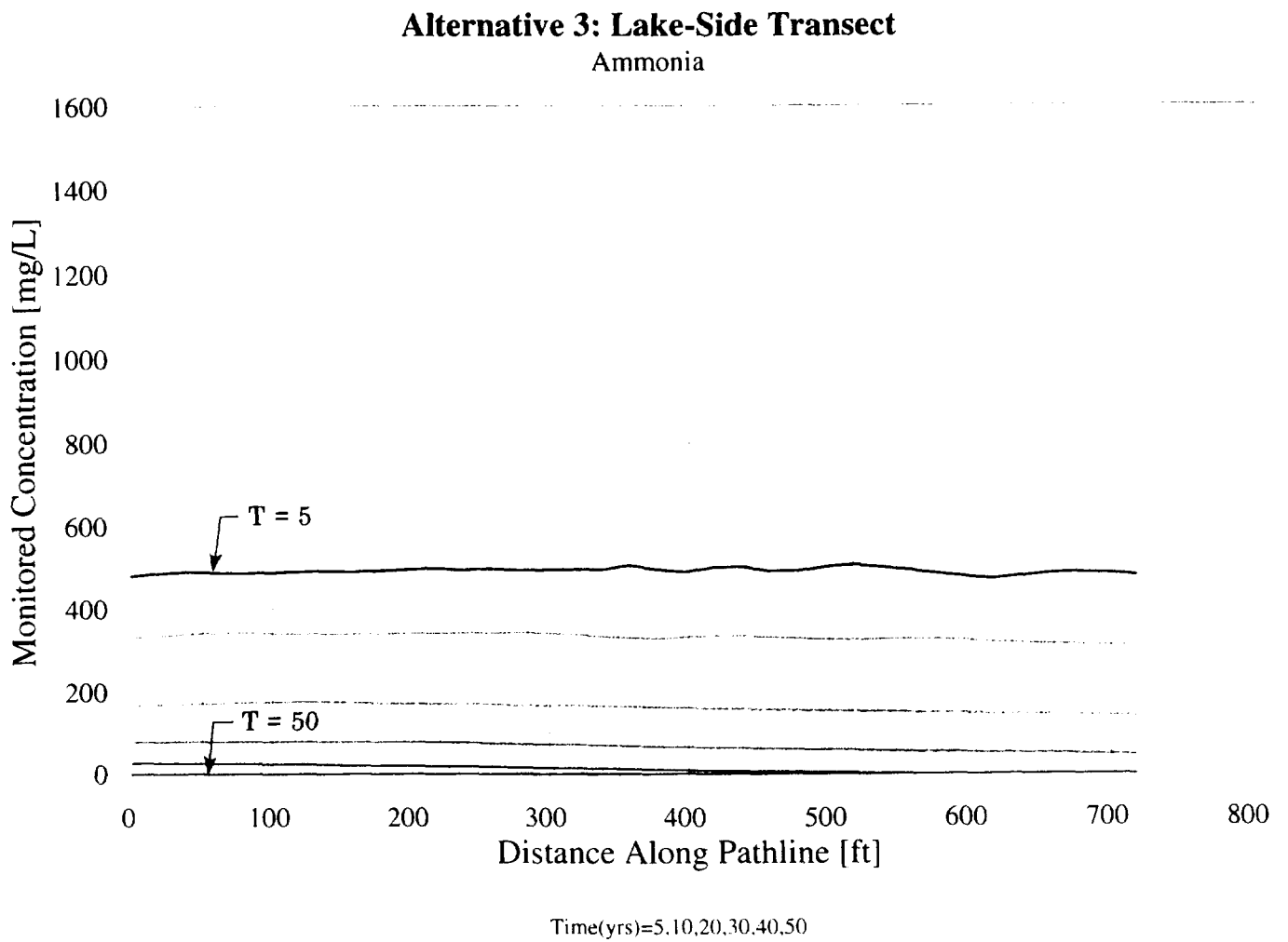
Figure 5-E-18

REMOVAL,
LAKE-SIDE TRANSECT, AMMONIA
(50% Cell Mass Removal)
Waukegan Manufactured Gas & Coke Plant Site

Alternative 3: Lake-Side Transect
Ammonia

Monitored Concentration [mg/L]

Distance Along Pathline [ft]

T = 5

T = 50

Time(yrs)=5,10,20,30,40,50
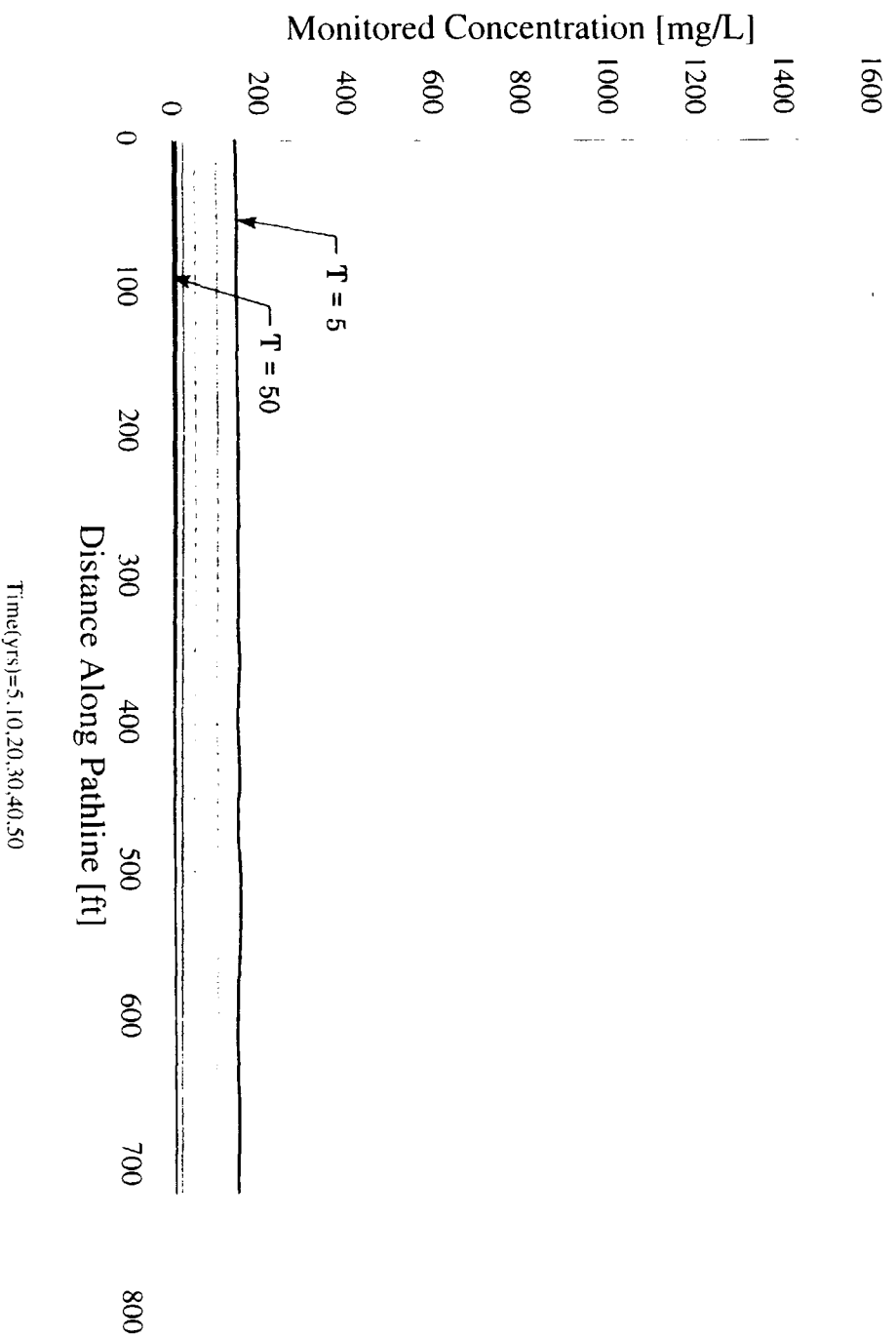
Figure 5-E-19
REMOVAL,
LAKE-SIDE TRANSECT, AMMONIA
(85% Cell Mass Removal)
Waukegan Manufactured Gas & Coke Plant Site

Alternative 3: Lake-Side Transect
Total Phenols

Time(yrs)=5,10,20,30,40,50,70
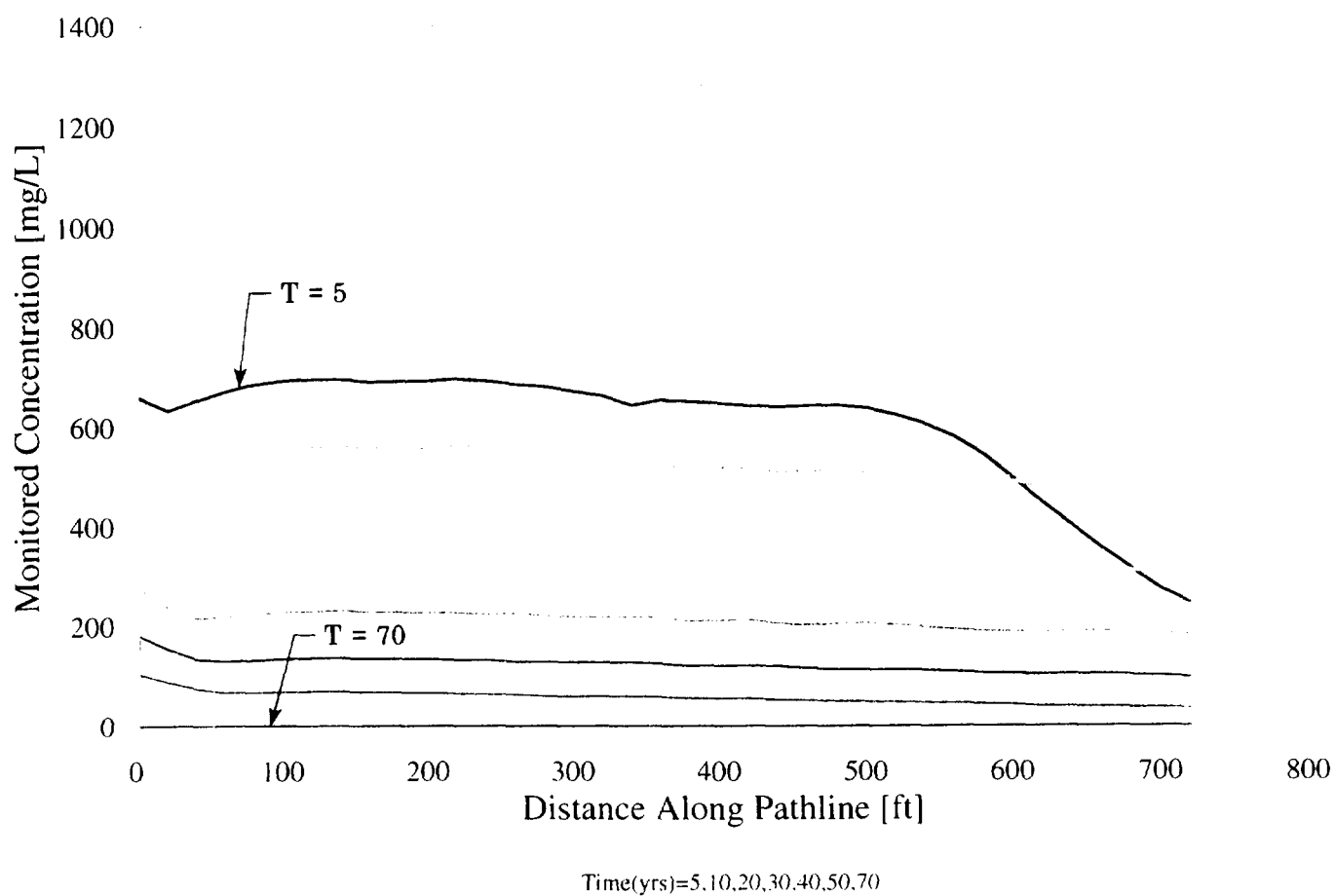
Figure 5-E-20

REMOVAL,
LAKE-SIDE TRANSECT, TOTAL PHENOLS
(35% Cell Mass Removal)
Waukegan Manufactured Gas & Coke Plant Site

Alternative 3: Lake-Side Transect
Total Phenols
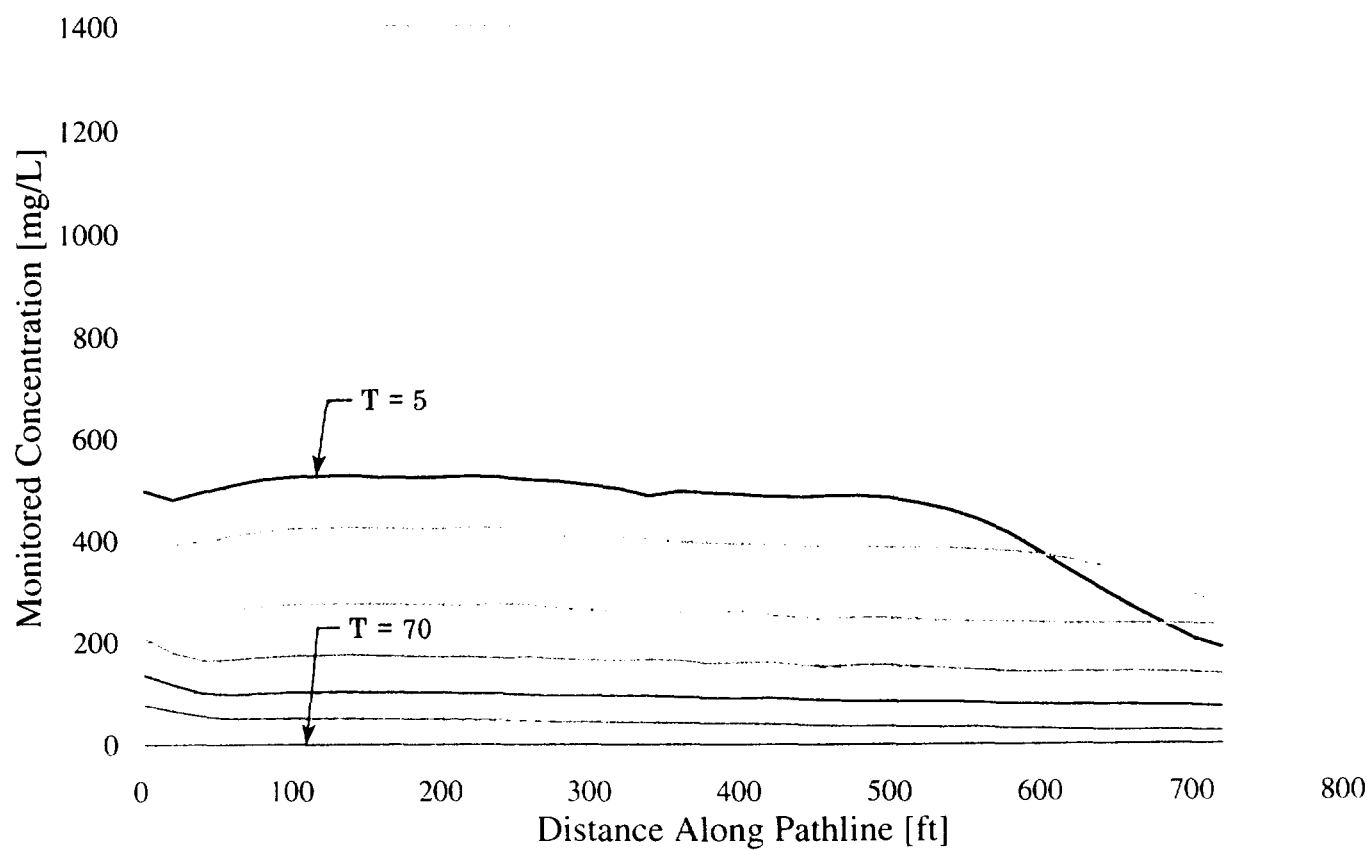
Time(yrs)=5,10,20,30,40,50,70

Figure 5-E-21

REMOVAL,
LAKE-SIDE TRANSECT, TOTAL PHENOLS
(50% Cell Mass Removal)
Waukegan Manufactured Gas & Coke Plant Site

Alternative 3: Harbor-Side Transect
Arsenic (Entire Transect Treatment)

Monitored Concentration [mg/L]

Distance Along Pathline [ft]

T = 5

T = 90

Time(yrs)=5,10,20,30,40,50,70,90
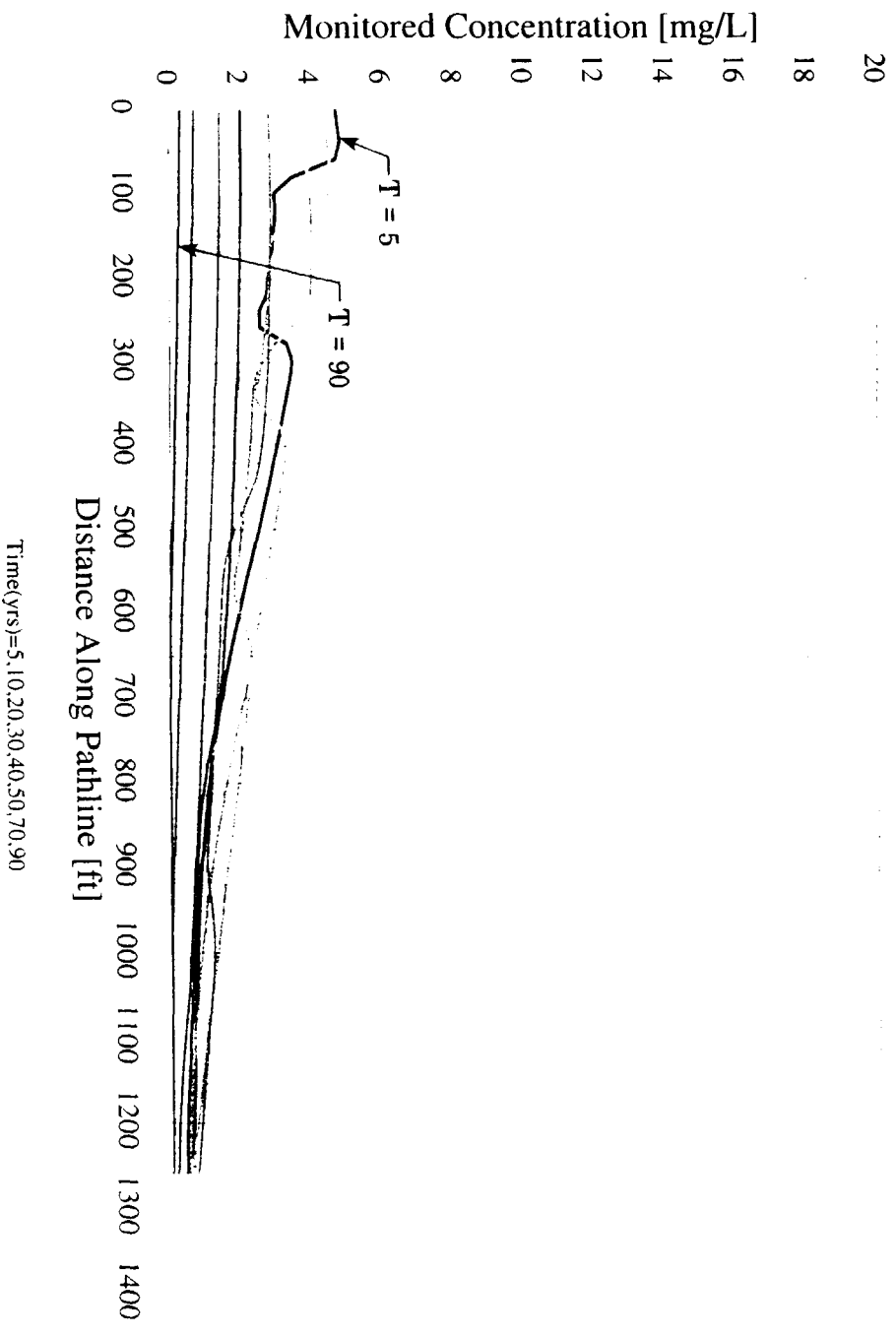
Figure 5-E-23
HARBOR-SIDE, ENTIRE TRANSECT TREATMENT
ARSENIC
Waukegan Manufactured Gas & Coke Plant Site
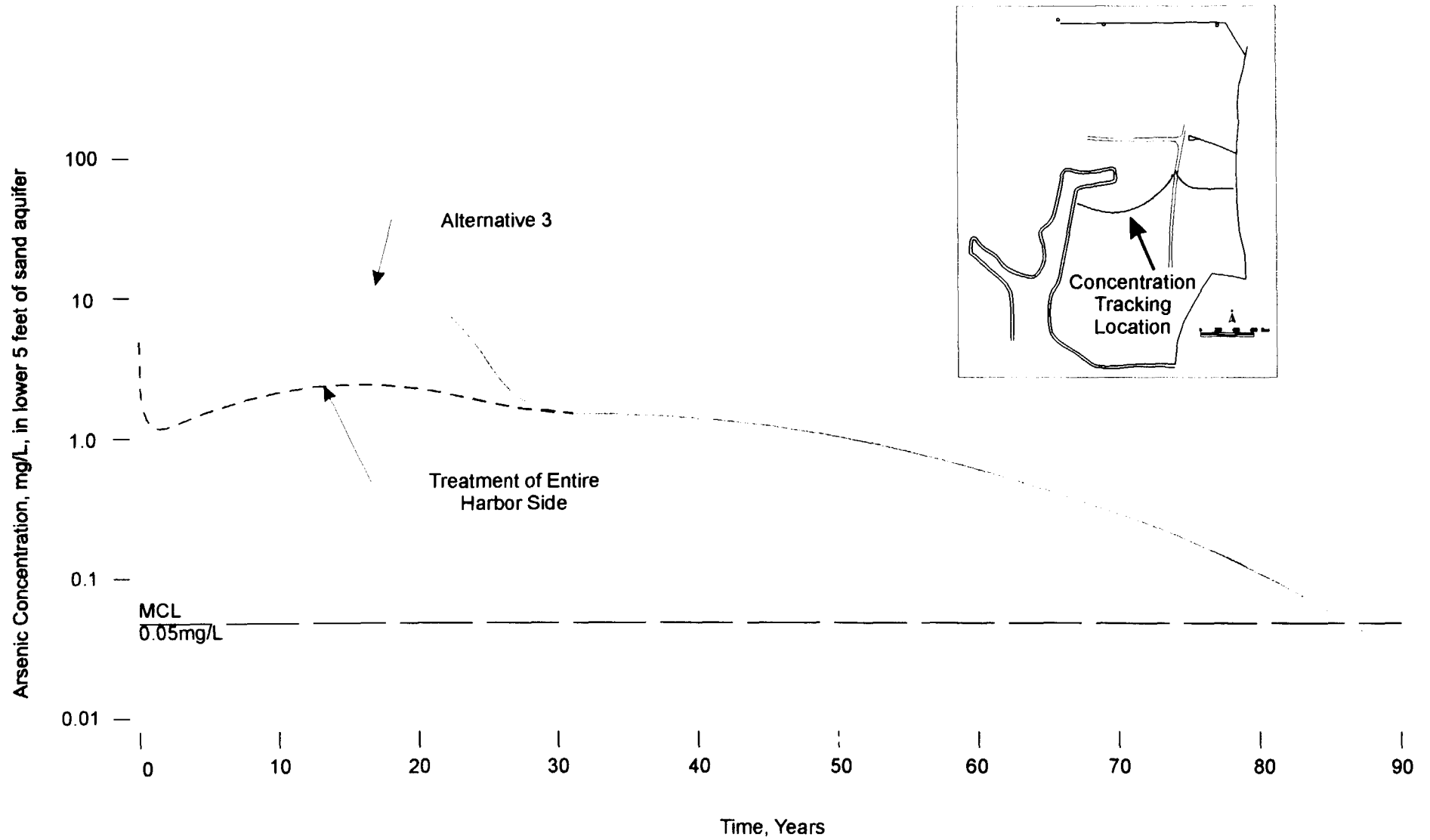
Figure 5-E-24

COMPARISON OF TREATMENT
AND NATURAL ATTENUATION
HARBOR SIDE, ARSENIC
Waukegan Manufactured Gas & Coke Plant Site

Alternative 3: Harbor-Side Transect
Ammonia

Time(yrs)=5,10,20,30,40,50,70,90
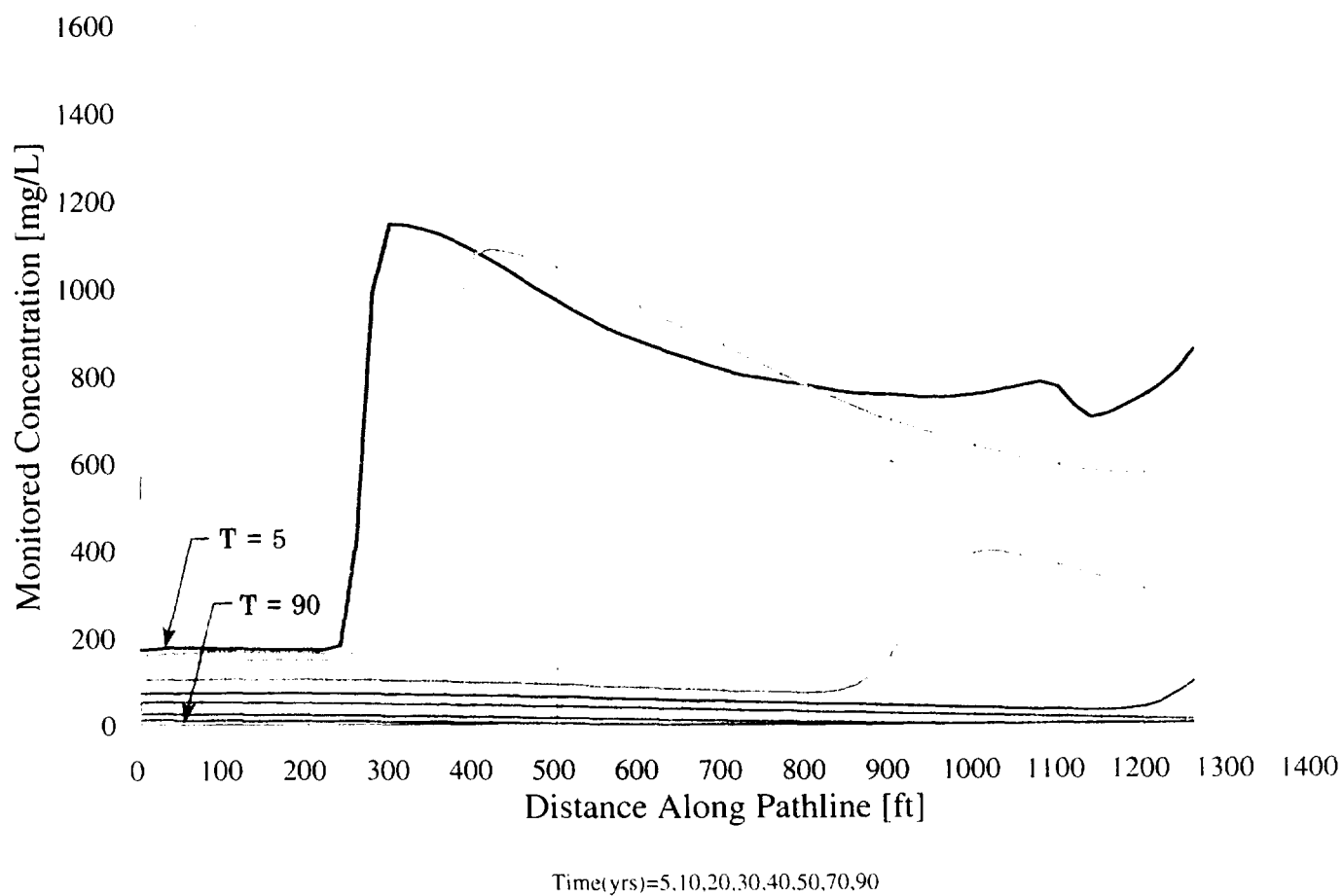
Figure 5-E-25

REMOVAL,
HARBOR-SIDE TRANSECT, AMMONIA
(85% Cell Mass Removal)
Waukegan Manufactured Gas & Coke Plant Site

Alternative 3: Harbor-Side Transect
Ammonia

Time(yrs)=5,10,20,30,40,50,70,90
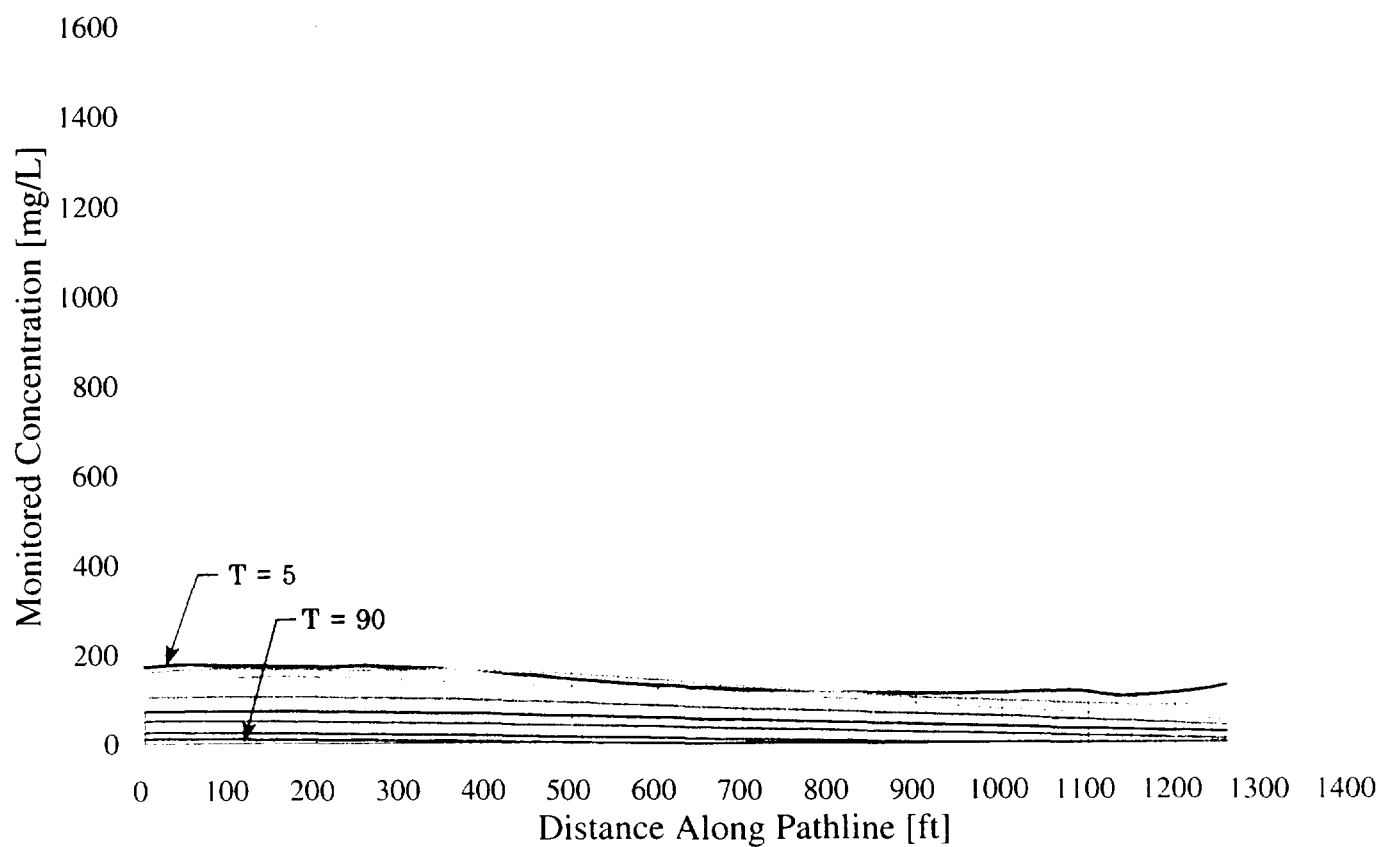
Figure 5-E-26

HARBOR-SIDE,
ENTIRE TRANSECT TREATMENT, AMMONIA
Waukegan Manufactured Gas & Coke Plant Site

Alternative 3

Treatment of Entire Harbor Side

Concentration Tracking Location

Ammonia Concentration, mg/L, in lower 5 feet of sand aquifer

Time, Years
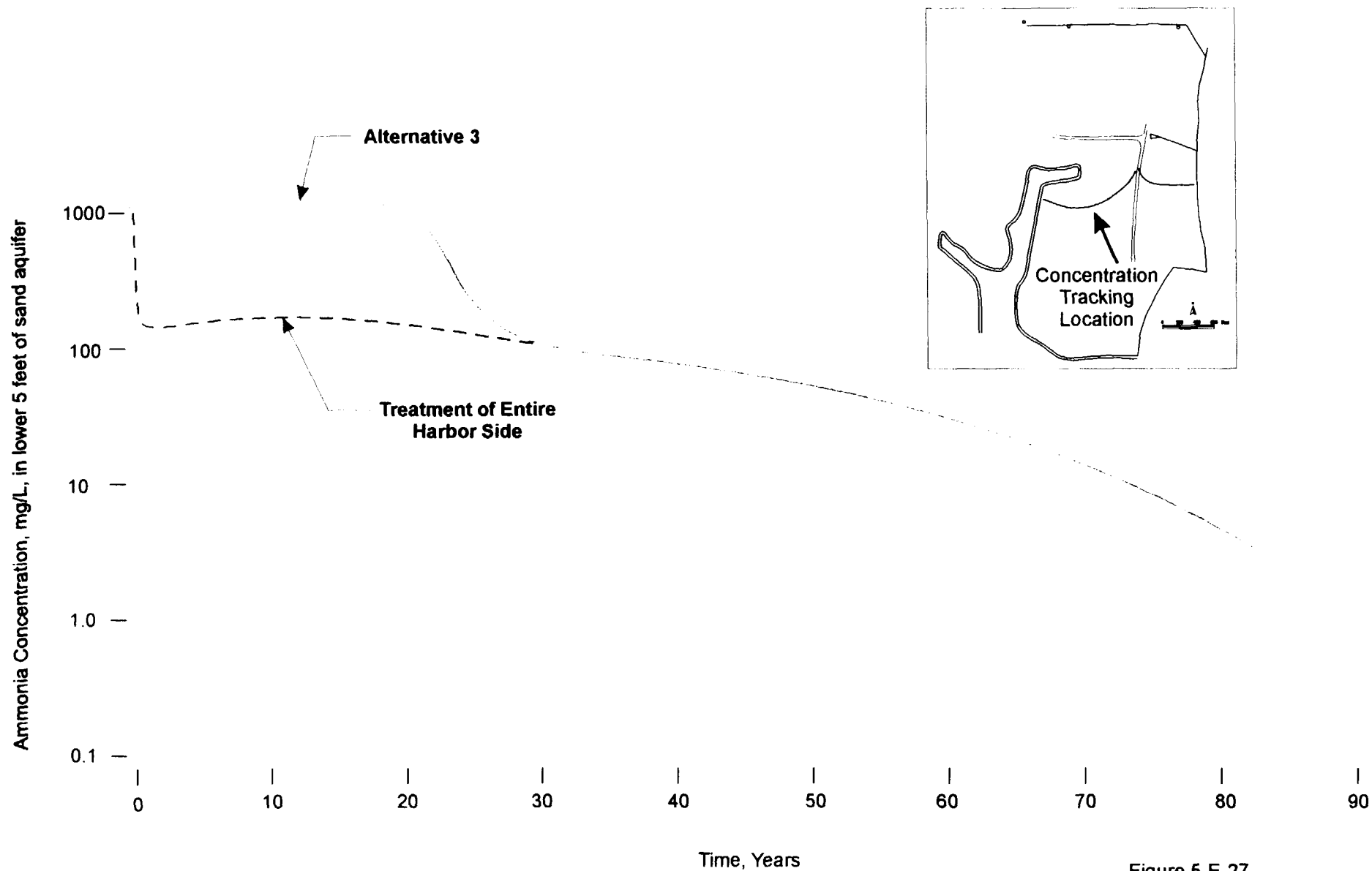
Figure 5-E-27

COMPARISON OF TREATMENT
AND NATURAL ATTENUATION
HARBOR SIDE, AMMONIA
Waukegan Manufactured Gas & Coke Plant Site
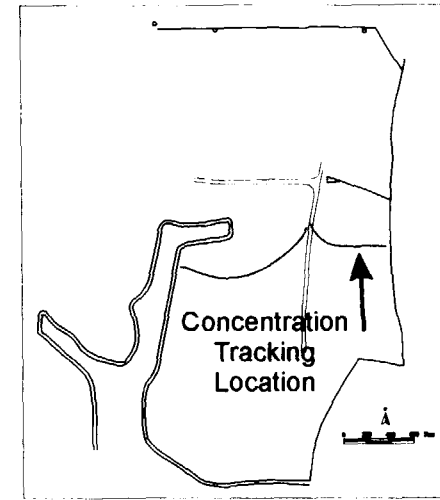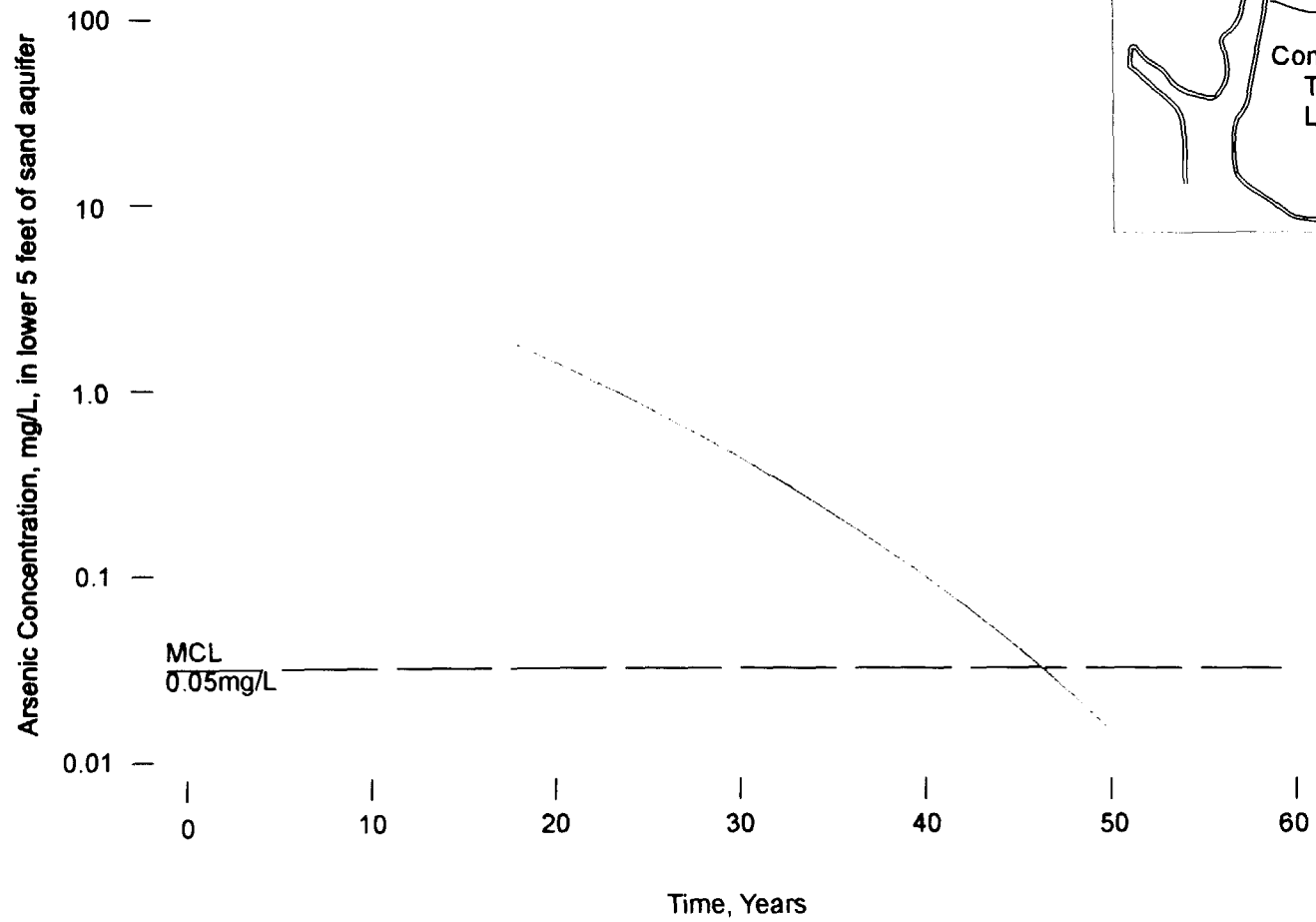
Figure 5-E-28

LAKE-SIDE NATURAL ATTENUATION
AFTER CELL TREATMENT, ARSENIC
Waukegan Manufactured Gas & Coke Plant Site
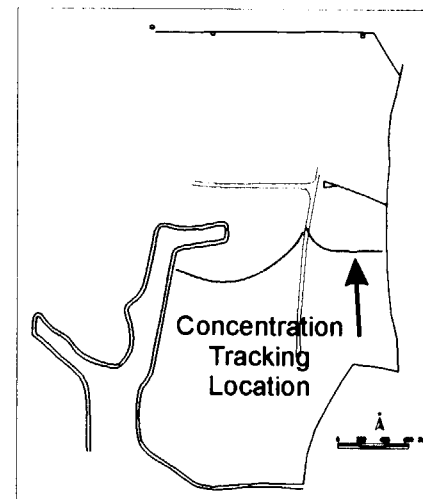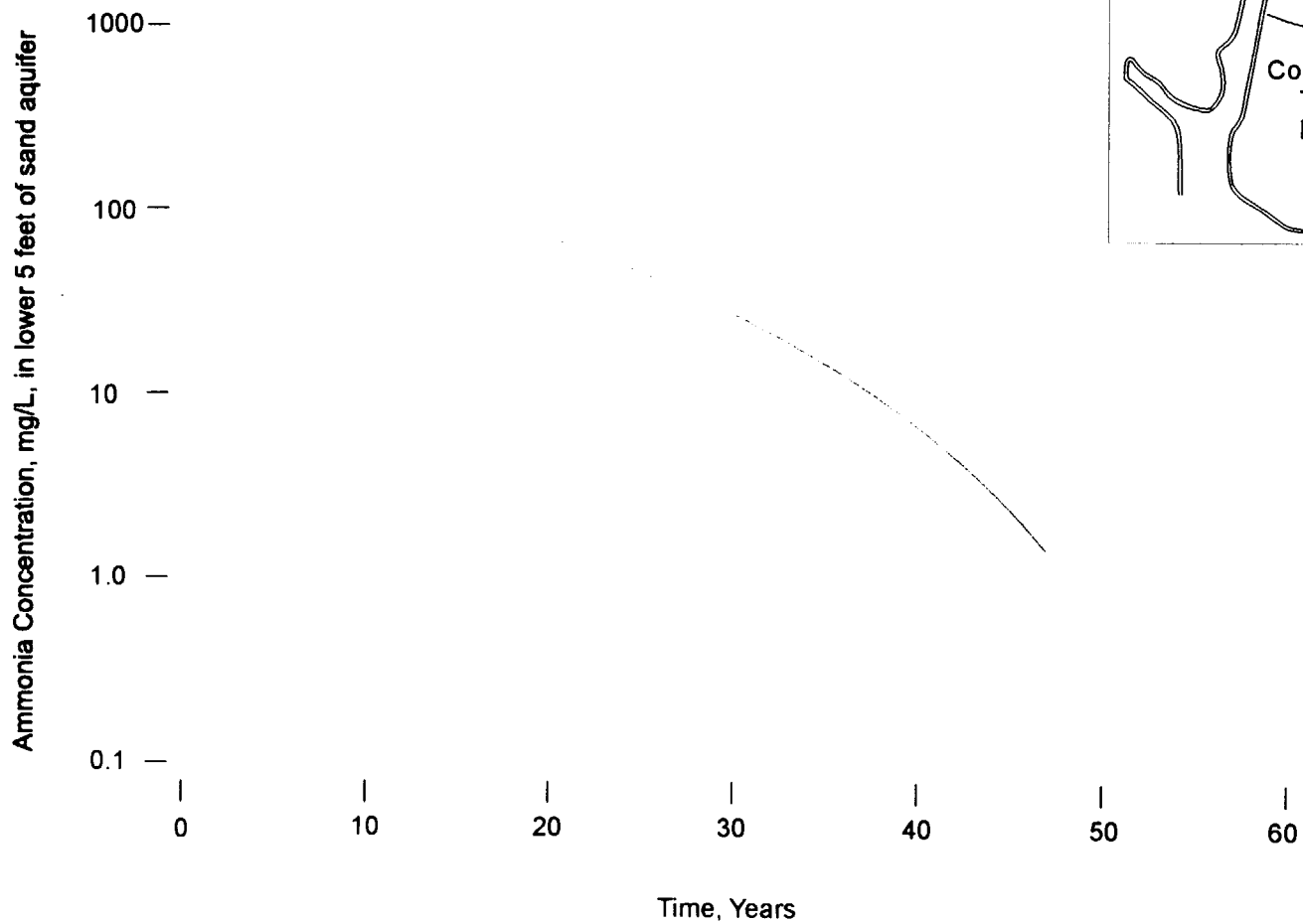
Concentration
Tracking
Location

Ammonia Concentration, mg/L, in lower 5 feet of sand aquifer

1000 —

100 —

10 —

1.0 —

0.1 —

0   10   20   30   40   50   60

Time, Years

Figure 5-E-29

LAKE-SIDE NATURAL ATTENUATION
AFTER CELL TREATMENT, AMMONIA
Waukegan Manufactured Gas & Coke Plant Site
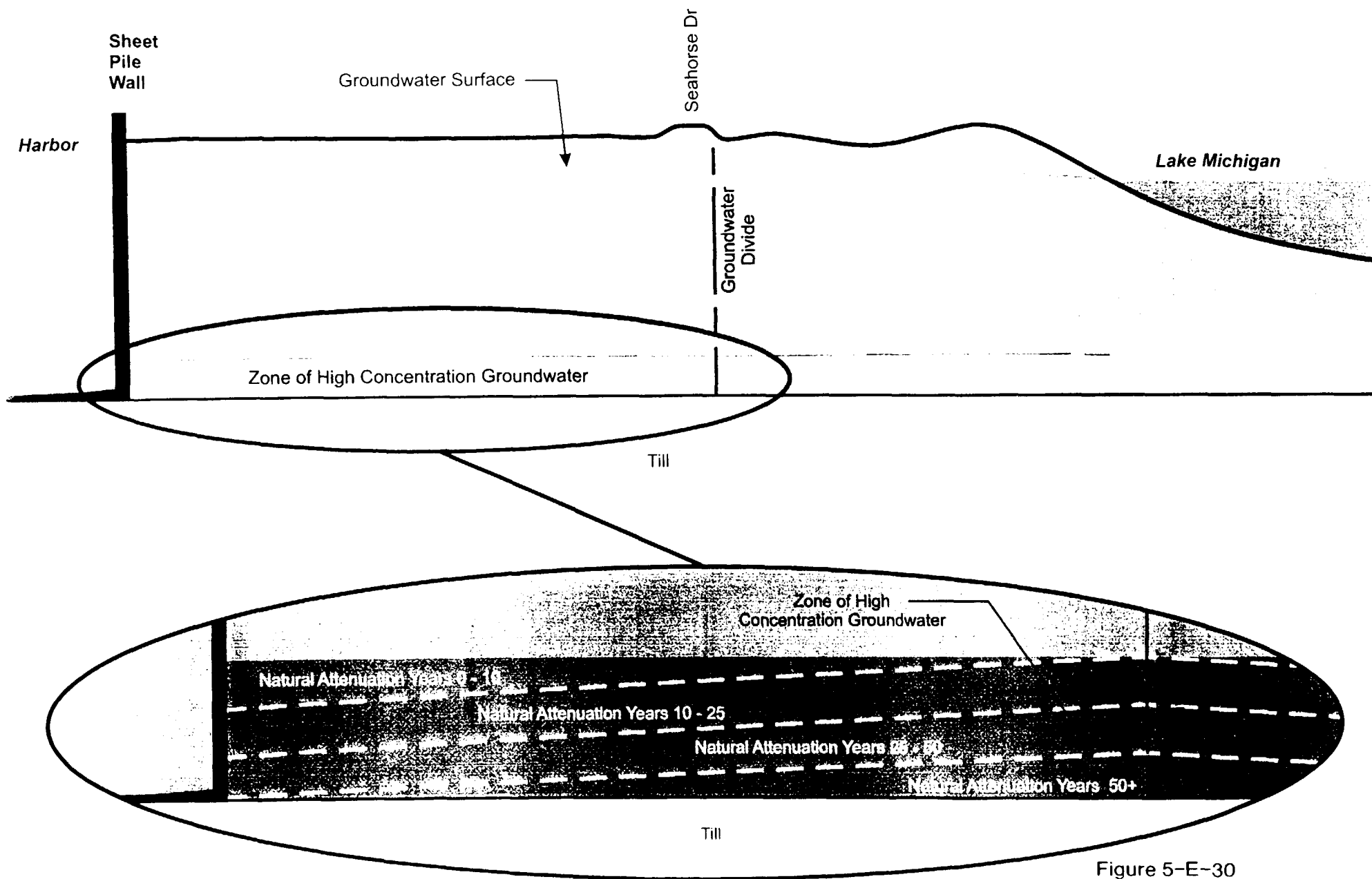
Figure 5-E-30

ESTIMATED PROGRESSION OF
NATURAL ATTENUATION
Waukegan Manufactured Gas & Coke Plant Site

Attachment 1

Natural Attenuation of Phenols in the WMGCP Aquifer

Introduction

The lower 5 feet of the 30-ft thick sandy aquifer at the Waukegan Manufactured Gas and Coke Plant (WMGCP) site is contaminated with elevated concentrations of phenols, ammonia, thiocyanate, arsenic, chloride, sulfate, and other substances. The deep groundwater chemically resembles the wastewater generated by coal conversion or coal gasification processes. Aerobic and anaerobic biological processes can treat coal conversion wastewater, and thus, should be able to treat the WMGCP site's deep groundwater. However, the continued presence of phenols in the deep groundwater suggests that anaerobic phenol-degrading microorganisms are inhibited in the deep groundwater. Possible inhibitory agents include phenol, *ortho*-cresol, ammonia, and arsenic.

Examination of the 1997 beach transect data indicated that the deep-groundwater phenols are biodegraded by sulfate-reducing bacteria. However, activity appears to be limited to regions 5 to 15 feet above the beach transect's till aquitard. Figures 1-1 and 1-2 illustrate the overlap of the sulfate and phenols concentration "holes", which suggests that sulfate-reducing bacteria are biodegrading the phenols. Concentrations of all potential chemical inhibitors are assumed to decrease with distance above the till. The location of the sulfate-reducing activity suggests that the matrix inhibitory factor (MIF) of the deep groundwater must be sufficiently diluted to allow biological activity. The distance of the anaerobic biologically active zone above the till suggests that the deep-groundwater MIF concentration has been diluted by about an order of magnitude. However, because of the self-inhibitory nature of phenols, the degree of dilution corresponding to MIF inhibition threshold concentration could be less than an order of magnitude.

One of the remedies evaluated for groundwater remediation in the Feasibility Study is the use of phased ex-situ treatment cells. This groundwater treatment system removes the contaminated groundwater from the aquifer, treats the groundwater above ground in a two-step process, and reinjects the treated groundwater into the aquifer. Coupled with the phased treatment cells is a phytoremediation cap that reduces the infiltration of water by about 50 percent. Two pore volumes of groundwater from each 100-ft by 200-ft treatment cell will be treated and reinjected. The anticipated result is that in the lower 5 feet of the aquifer, concentrations of non-retarded chemical species will decrease by 85 percent and the concentration of retarded chemicals (*e.g.*, phenols) will decrease by 50 percent. The groundwater in the upper 25 feet of the aquifer will have the same chemical characteristics as the reinjected water from the groundwater treatment system. After groundwater treatment, the natural attenuation of the remaining aquifer contaminants will be monitored through groundwater sampling and analysis.

The goal of this study is to evaluate on a conceptual level the time required for the complete anaerobic biodegradation of deep-groundwater phenols once the MIF concentration has been reduced below its inhibition threshold concentration. The evaluation uses a 1-dimensional transport model to estimate the time requirements for the intrinsic anaerobic biological processes to remove the phenols along a 200-ft long transect. The model considers horizontal advective transport, longitudinal (horizontal) mixing, the adsorption of phenols to aquifer solids, anaerobic biodegradation performed by sulfate-reducing bacteria, and anaerobic biodegradation by a methane-producing consortia of bacteria.

A basic premise of this evaluation is that no anaerobic biodegradation occurs when the MIF concentration is greater than its inhibition threshold concentration. When the MIF concentration relative to its inhibition threshold concentration is less than 1, the self-inhibition kinetics of phenols (*i.e.*, Haldane kinetics), the concentrations of available electron acceptors (sulfate, carbon dioxide), and the concentrations of capable bacteria determine the rate at which phenols are biodegraded.

A second fundamental assumption is that there is always a small inoculum of capable bacteria present in the aquifer. Once favorable conditions exist, the previously inactive bacteria will begin to biodegrade the phenols. For example, sulfate-reducing bacteria capable of utilizing the phenols as growth substrate will be modeled as active bacteria when the relative MIF concentration is less than 1, sulfate anions are available, and the phenols (substrate) concentration is greater than S_{min} and less than S_{max}. S_{min} and S_{max} are parameters derived from Haldane inhibition kinetics. A phenols concentration below S_{min} can not provide sufficient energy for net bacterial growth. Phenols concentrations above S_{max} are sufficiently inhibitory to prevent net bacterial growth.

The modeling results suggest that once the concentration of the matrix inhibition factor (MIF) drops below its inhibition threshold concentration, anaerobic bacteria can rapidly biodegrade the deep-groundwater phenols. The modeling results suggest that anaerobic bacteria can biodegrade virtually all of deep-groundwater phenols within 3 years after removal of matrix inhibition.

Modeling Approach

The influent to the modeled 200-ft long transect is assumed to be a phased ex-situ treatment cell. Prior to treatment of the two pore volumes of groundwater with in the treatment cell, the influent to the modeled transect was essentially that of the existing deep groundwater. The pre-treatment influent phenols and sulfate concentrations were 940 mg/L and 400 mg/L, respectively. The influent MIF concentration relative to its inhibition threshold concentration was 1.1. Pre-treatment conditions were assumed to exist sufficiently long to create transect concentrations equal to the influent concentrations (transport alone). Operation of the treatment cell is assumed to instantaneously reduce the influent concentrations for the modeled transect. As indicated in Table 1-1, the post-treatment influent phenols and sulfate concentrations were 470 and 193 mg/L, respectively. The influent MIF concentration relative to its inhibition threshold concentration was 0.9.

Table 1-1. Influent concentrations for the modeled transect.

Parameter	Units	Pre-Treatment	Post-Treatment
Phenols concentration	mg/L	940	470
Sulfate concentration	mg/L	400	193
Relative MIF concentration	unitless*	1.1	0.9

* the relative MIF concentration is equal to its concentration divided by its inhibition threshold concentration

In the 1-dimensional transport model with anaerobic biodegradation, the mass balance equations for the total phenols, sulfate, and MIF have the following form:

$$\frac{\partial S_{phnl}}{\partial t} = D_x \frac{\partial^2 S_{phnl}}{\partial x^2} - u_x \frac{\partial S_{phnl}}{\partial x} + \frac{\rho_b}{n} \frac{\partial S_{phnl,s}}{\partial t} + R_{SRB,phnl} + R_{MPC,phnl} \tag{1}$$

$$\frac{\partial S_{SO_4}}{\partial t} = D_x \frac{\partial^2 S_{SO_4}}{\partial x^2} - u_x \frac{\partial S_{SO_4}}{\partial x} + R_{SRB,SO_4} \tag{2}$$

$$\frac{\partial S_{MIF}}{\partial t} = D_x \frac{\partial^2 S_{MIF}}{\partial x^2} - u_x \frac{\partial S_{MIF}}{\partial x} \tag{3}$$

in which S_{phnl} is the phenols concentration (g_p/m^3), S_{SO_4} is the sulfide concentration (g_s/m^3), S_{MIF} is the relative MIF concentration (unitless), t is time (days), D_x is the longitudinal dispersion coefficient (ft^2/day), x is distance (ft), u_x is the horizontal linear velocity (ft/day), ρ_b is the bulk density of the aquifer (g/cm^3), n is the aquifer porosity (mL/cm^3), $S_{phnl,s}$ is the concentration of phenols adsorbed to the aquifer solids (mg/g solids), R_{SRB} is the anaerobic biological reaction rate term due to sulfate-reducing bacteria (g_p m^{-3} d^{-1}), and R_{MPC} is the anaerobic biological rate term due to phenol-degrading bacteria found in the methane-producing consortia (g_p m^{-3} d^{-1}). The longitudinal dispersion coefficient is expressed as the sum of two components

$$D_x = \alpha_x u_x + \omega D_w \tag{4}$$

in which α_x is the longitudinal dispersivity (ft), D_w is the molecular diffusion coefficient for the modeled chemical in water (ft^2/day), and ω is the empirical coefficient that takes into account the effect of porous media on water-phase diffusion (unitless). The diffusion coefficient for phenol was calculated from the Wilke-Chang correlation (Perry and Green, 1984). The diffusion coefficient for the MIF was assumed equal to that of chloride. The diffusion coefficients for sulfate and chloride were obtained from Cussler (1984). The assumed values of α_x and ω were 25 ft and 0.5, respectively (Freeze and Cherry, 1984).

Each chemical mass balance equation has two boundary conditions for the modeled transect: the influent boundary condition and the downgradient boundary. The influent boundary condition is defined by a Cauchy-type equation.

$$u_x S_{inf} = u_x S_o - D_x \frac{\partial S}{\partial x} \tag{5}$$

in which S_{inf} is the chemical's influent concentration entering the modeled transect by the advective movement of water (g/m^3), S_o is the chemical concentration at the first node within the transect (g/m^3). The downgradient boundary condition assumes a zero concentration gradient,

$$\frac{\partial S}{\partial x} = 0. \tag{6}$$

The distribution of phenols between the dissolved and adsorbed phases was determined after each transport and biodegradation calculation by a three-step process. First, the total mass of phenols in a unit volume of aquifer was calculated based on the water-phase concentration and adsorbed-phase concentration from the previous time step. Second, the new water-phase concentration was calculated from the mass and various adsorption-related parameters. Third, the

new adsorbed-phase concentration was calculated from the new water-phase concentration and the partition coefficient. The three step process is described by the following three equations:

$$mass = \frac{nS_{phnl}}{1000} + \rho_b S_{phnl,s} \tag{7}$$

$$S_{phnl} = \frac{1000\, mass}{n + \rho_b K_d} \tag{8}$$

$$S_{phnl,s} = \frac{S_{phnl} K_d}{1000} \tag{9}$$

in which *mass* is the sum of the water-phase phenols mass and the adsorbed-phase phenols mass in a unit volume of aquifer (mg/cm^3), K_d is the partition coefficient (mL/g soil), and 1000 is a conversion constant with the units of mL/L. The assumed values of n, ρ_b, and K_d are 0.38 mL/cm^3, 1.7 g soil/cm^3, and 0.54 mL/g soil (Barr, 1995), which together correspond to a retardation factor of 3.42.

For the self-inhibitory phenols, the anaerobic reaction rate terms $R_{SBR,phnl}$ and $R_{MPC,phnl}$ in equation (1) and the $R_{SBR,so4}$ term in equation (2) follow Haldane inhibition kinetics and the strictly macroscopic model of subsurface microbial kinetics described by Odencrantz et al. (1990):

$$R_{SRB,phnl} = \left(\frac{-q_{max,SRB} X_{SRB} S_{phnl}}{K_{phnl,SRB} + S_{phnl} + \dfrac{S_{phnl}^2}{K_{i,SRB}}} \right) \left(\frac{S_{so_4}}{K_{so_4} + S_{so_4}} \right) \tag{10}$$

$$R_{MPC,phnl} = \frac{-q_{max,MPC} X_{MPC} S_{phnl}}{K_{phnl,MPC} + S_{phnl} + \dfrac{S_{phnl}^2}{K_{i,MPC}}} \tag{11}$$

$$R_{SRB,so_4} = \left(\frac{-\gamma q_{max,SRB} X_{SRB} S_{phnl}}{K_{phnl,SRB} + S_{phnl} + \dfrac{S_{phnl}^2}{K_{i,SRB}}} \right) \left(\frac{S_{so_4}}{K_{so_4} + S_{so_4}} \right) - 2.13 b X_{SBR} \left(\frac{S_{so_4}}{K_{so_4} + S_{so_4}} \right) \tag{12}$$

in which X_{SRB} is the "water-phase" concentration of phenol-degrading sulfate-reducing bacteria (g$_x$/m^3), X_{MPC} is the "water-phase" concentration of phenol-degrading bacteria in a methane-producing consortia of microorganisms (g$_x$/m^3), q_{max} is the maximum specific utilization rate coefficient (g$_p$ mg$_x^{-1}$ day^{-1}), K_{phnl} is the Monod half-velocity coefficient for phenols (g$_p$/m^3), K_{so4} is the Monod half-velocity coefficient for sulfate (g$_s$/m^3), γ is the ratio of sulfate mass consumed per mass of phenols consumed (2.8 g$_s$/g$_p$), and b is the first-order biomass decay coefficient (1/day). The "water-phase" biomass concentration means that the concentration is expressed in terms of bacterial mass per unit of water volume. However, the bacteria are attached to the aquifer media.

The equations describing the accumulation of the two types of phenol-degrading bacteria have the following form:

$$R_{SRB} = \frac{\partial X_{SRB}}{\partial t} = \left(\frac{Y_{SRB} q_{max.SRB} X_{SRB} S_{phnl}}{K_{phnl.SRB} + S_{phnl} + \frac{S_{phnl}^2}{K_{i.SRB}}} \right) \left(\frac{S_{so_4}}{K_{so_4} + S_{so_4}} \right) - b X_{SBR} \tag{13}$$

$$R_{MPC.phnl} = \frac{\partial X_{MPC}}{\partial t} = \frac{Y_{MPC} q_{max.MPC} X_{MPC} S_{phnl}}{K_{phnl.MPC} + S_{phnl} + \frac{S_{phnl}^2}{K_{i.MPC}}} - b X_{MPC} \tag{14}$$

in which R_{SRB} is the net accumulation rate of phenol-degrading sulfate-reducing bacteria ($g\,m^{-3}day^{-1}$), R_{MPC} is the accumulation rate of phenol-degrading bacteria in a methane-producing consortia of microorganisms ($g_x\,m^{-3}\,day^{-1}$), and Y is the true yield (g_x/g_p).

The anaerobic biodegradation kinetics coefficients used in modeling the phenols along the 200-ft long transect are provided in Table 1-2. The values of q_{max} and b were corrected for aquifer temperature (*i.e.*, 12°C) by assuming a Q_{10} of 2. Q_{10} is the factor by which the rate of a process increases with a 10°C increase in temperature. The other coefficients did not vary with temperature.

Table 2. Kinetic coefficients at 20°C used in modeling anaerobic biodegradation of deep-groundwater phenols along the 200-ft long transect.

Coefficient	Units	Sulfate-Reducing Bacteria	Methane-Producing Consortia
Y	g_x/g_p	0.2	0.16[b]
q_{max}	$g_p\,g_x^{-1}\,day^{-1}$	2.0[a]	0.65[b]
K_{phnl}	g_p/m^3	5.0[a]	20[c]
K_i	g_p/m^3	75	263[c]
b	1/day	0.01	0.01
K_{so_4}	g_s/m^3	6.5	---
S_{min}	g_p/m^3	0.13	2.13
S_{max}	g_p/m^3	2925	2470
S^*	g_p/m^3	19.4	72.5

Note: S^* is the phenols concentration beyond which the rate of phenols biodegradation slows.
Sources: [a]Cookson (1995), [b]Suidan *et al.* (1988), and [c]Saéz *et al.* (1991).

The simultaneous solution of the three mass balance equations and the associated biodegradation equations followed the operator-splitting algorithm described in Odencrantz *et al.* (1990). First, the phenols, sulfate, and MIF transport equations were each solved separately for a

single time step (Δt) using an implicit finite-difference scheme (Chapra and Canale, 1988). The time step was 1 day. The resulting three tridiagonal matrices were solved using the Thomas algorithm (Pinder and Gray, 1977). Second, the solution of the transport step was used as the initial conditions for the biodegradation step. Equations (10) through (14) were solved simultaneously using a fourth-order Runge-Kutta algorithm (Chapra and Canale, 1988) over an elapsed time of Δt using a time step equal to 1/24th of Δt. The solution of the biodegradation component of the operator-splitting approach was used as the initial conditions for the next transport component over the next Δt.

Modeling Results

The modeled 200-ft long transect had an uniform linear groundwater velocity of 0.252 ft/day, which is about the expected average linear velocity for groundwater traveling toward Lake Michigan after installation of the proposed phytoremediation cap. The phytoremediation cap is expected to reduce the rate of infiltration by 50 percent. The time required for groundwater to travel the 200-ft long transect is 794 days or 2.17 years.

The predicted concentrations of the matrix inhibition factor (MIF) relative to its inhibition threshold as a function of time after the assumed instantaneous reduction in influent concentrations is provided in Figure 1-3. Initially, the relative MIF concentration of 1.1 exists throughout the modeled transect. Because the initial relative MIF concentration is greater than 1, the model assumes that no biological activity occurs along the transect. Operation of the treatment cell is assumed to instantaneously reduce the influent concentrations for the modeled transect. Figure 1-3 indicates the relative MIF concentration throughout the transect drops below 1 within 2 years after the influent relative MIF concentration decreases from 1.1 to 0.9. Thus, within 2 years of the influent concentration reduction, the matrix inhibition of the anaerobic biodegradation of the phenols has been removed.

As illustrated in Figure 1-4, if no anaerobic biodegradation of the phenols occurred along the 200-ft long transect, then the phenols concentrations would slowly respond to the reduction in influent concentrations. The retardation of the phenols by aquifer solids is responsible for the slow response to changes in influent concentrations. Without biodegradation, the smallest possible phenols concentration would equal the reduced influent concentration of 470 mg/L.

The potential impact of anaerobic biodegradation on the transect phenols concentrations is illustrated in Figures 1-5, 1-6, and 1-7. Anaerobic biodegradation is assumed possible when the relative MIF concentrations drop below 1, which is the case for the entire transect 2 years after the influent concentration reduction. Figure 1-5 indicates that anaerobic biodegradation has a slight impact on transect phenols concentrations 2 years after the influent concentration reductions. Anaerobic biodegradation occurs because the relative MIF concentrations are less than 1. However, the concentrations of capable bacteria remain small and the concentration of the self-inhibitory phenols is high, which limits the effect of anaerobic biodegradation on the transect phenols concentrations.

Figure 1-6 indicates that within 4 years after the influent concentration reductions, anaerobic biodegradation has removed much of the phenols from the first half of the transect. The relative MIF concentrations in the first half of the transect were reduced below 1 within 1 year of the influent concentration reductions. Thus, the modeling results illustrated in Figure 1-6 suggest that 3 years of time after removal of the matrix inhibition is required for the phenols-degrading bacteria to accumulate sufficient biomass to remove virtually all of the phenols at a location in the aquifer. Figure 1-7 indicates that virtually all of the phenols mass has been removed from the modeled transect within 6 years after the influent concentration reductions.

The modeling results suggest that the phenols-degrading component of the methane-producing consortia are predominantly responsible for the biodegradation of the influent and residual phenols. The modeled distribution of phenol-degrading biomass 4 years after the influent concentration reductions is provided in Figure 1-8. Although Figure 1-8 indicates significant concentrations of sulfate-reducing bacteria, they play a small role in the removal of phenols from the transect. Figure 1-9 indicates that there is no sulfate present along the transect 4 years after the influent concentration reductions. Thus, the sulfate-reducing biomass indicated in Figure 1-8 are in endogenous decay, because there is no suitable electron acceptor present. The modeling results suggest that the methane-producing consortia account for more than 95 percent of the predicted removal of phenols at all points along the transect at 4 years after the influent concentration reductions.

Summary

A 1-dimensional transport model with anaerobic biodegradation was used to evaluate the time requirements for phenols biodegradation in the Waukegan Manufactured Gas and Coke Plant site aquifer following removal of matrix inhibition. A 200-ft long transect was evaluated considering horizontal advective transport, longitudinal mixing, the adsorption of phenols to aquifer solids, anaerobic biodegradation by sulfate-reducing bacteria, and anaerobic biodegradation by a methane-producing consortia of bacteria. The matrix inhibition factor (MIF) was modeled as a non-retarded chemical species. The model first loaded the transect with high concentrations of phenols (940 mg/L) and sulfate (400 mg/L), and with a MIF concentration relative to its inhibitory threshold of 1.1. Because the relative MIF concentration was initially greater than 1, the model assumed no anaerobic biodegradation occurred. At time zero, the phenols, sulfate, and relative MIF concentrations in the influent were instantaneously reduced to 470 mg/L, 193 mg/L, and 0.9, respectively.

The modeling results suggest that once the concentration of the matrix inhibition factor (MIF) drops below its inhibition threshold concentration, anaerobic bacteria can rapidly biodegrade the deep-groundwater phenols. The modeling results suggest that anaerobic bacteria can biodegrade virtually all of deep-groundwater phenols within 3 years after removal of matrix inhibition. The model assumed that a small inoculum of phenols-degrading bacteria (0.001 mg_x/L) are always present in the aquifer. For the selected kinetic coefficients and environmental conditions, the modeling results suggest that the methane-producing consortia of bacteria are predominantly responsible for the removal of phenols along the modeled transect. Thus, the observed removal of phenols by sulfate-reducing bacteria indicated by Figures 1-1 and 1-2 might represent only a small fraction of the total amount of phenols biodegradation occurring in the WMGCP site aquifer.

The predicted predominance of the methane-producing consortia of bacteria in determining the fate of phenols in the WMGCP site aquifer has an important implication on aquifer reclamation. The assumed scenario of reclamation is that the matrix inhibition factor is flushed from a unit volume of the aquifer and is eventually reduced below its inhibition threshold concentration. Provided that the phenols concentration is not above S_{max} for the methane-producing consortia, biodegradation of the phenols starts immediately. Phenols biodegradation does not have to wait for sulfate to arrive. Within 3 to 4 years after the removal of the matrix inhibition, the methane-producing consortia can accumulate sufficient phenols-degrading biomass to remove all of the residual phenols. Because sulfate is not required, phenols biodegradation can occur anywhere the matrix inhibition factor concentration has been sufficiently reduced. Thus, the anaerobic biologically active zones responsible for the natural attenuation of phenols in the WMGCP site aquifer can be located at two locations. The first location is within and downgradient of the groundwater treatment cells provided that the

groundwater treatment cell reduces the relative MIF concentration below 1. The second location is the fringe area above the deep groundwater, where infiltrating water can reduce the relative MIF concentration below 1 and result in the anaerobic biodegradation of the residual phenols.

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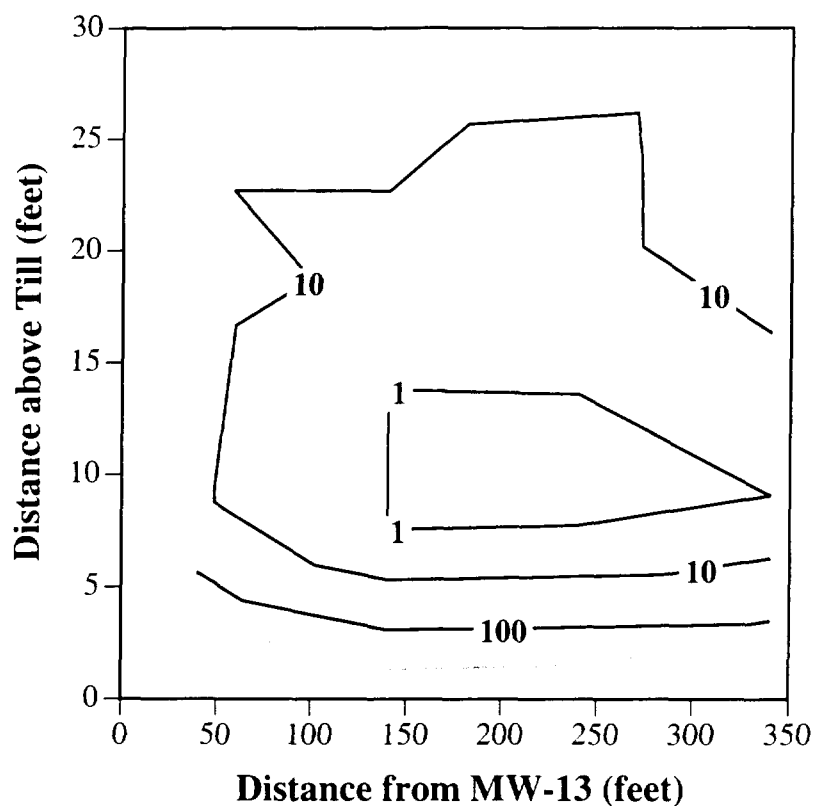
Figure 1-1. Observed sulfate concentrations (mg/L) along the beach transect. Note the sulfate concentration "hole" starting at 7.5 ft above the till.
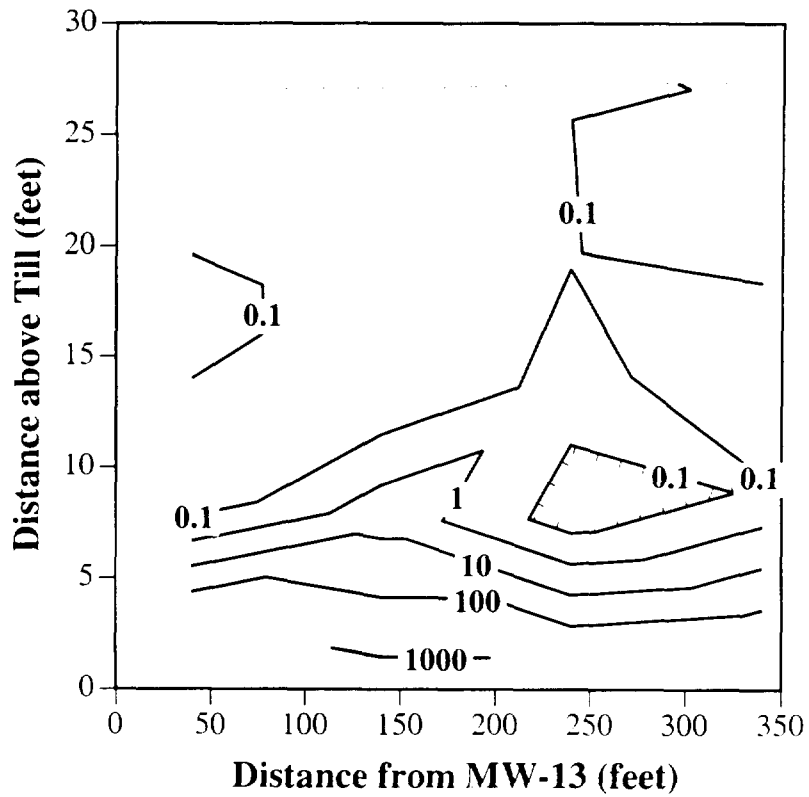
Figure 1-2. Observed concentration of phenols (mg/L) along the beach transect. Note the concentration "hole" starting at 7.5 ft above the till.
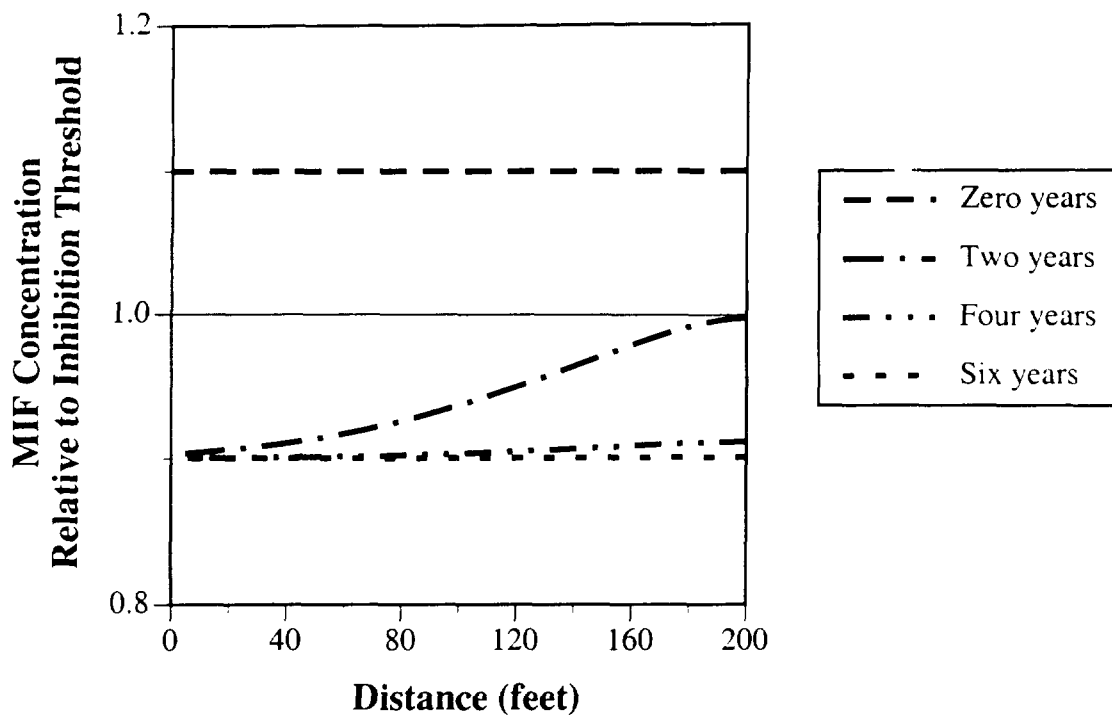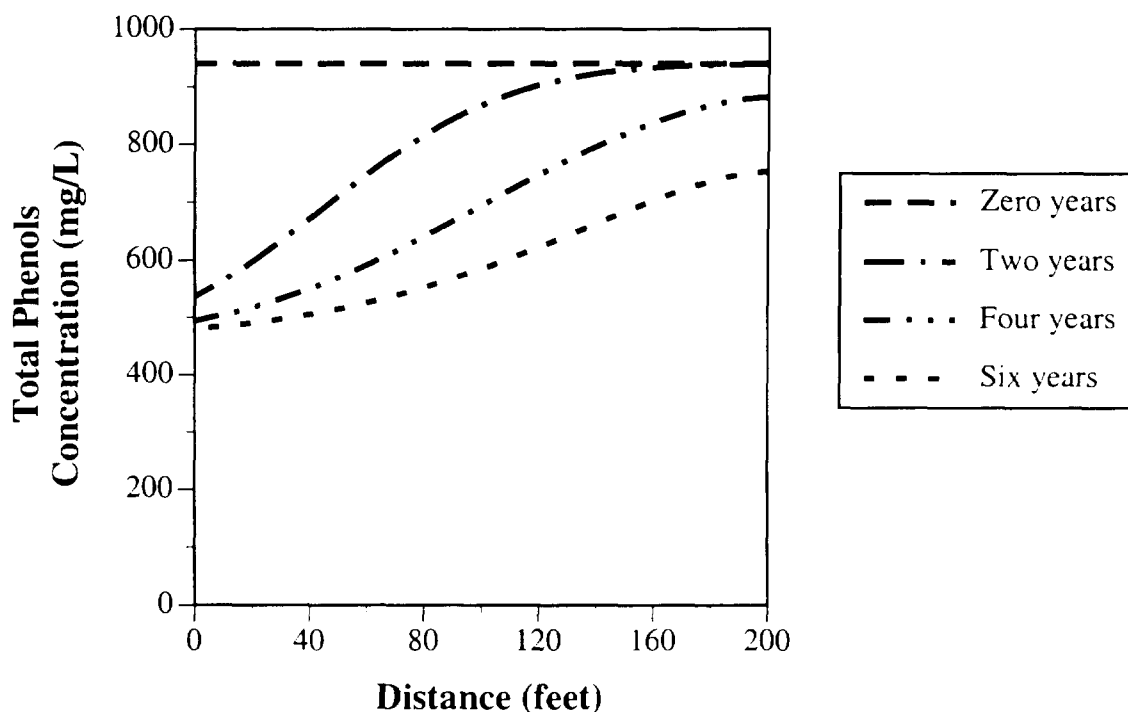
Figure 1-3. Predicted relative MIF concentrations along the 200-ft long transect as a function of time since the influent concentration reduction. Because MIF is assumed to be non-retarded, the transect concentrations approach the reduced influent concentration within 4 years.

Figure 1-4. Predicted total phenols concentrations along the 200-ft long transect as a function of time since the influent concentration reduction assuming no anaerobic biodegradation (transport alone). Because the phenols are retarded by the aquifer solids, the transect phenols concentrations slowly approach the reduced influent concentration of 470 mg/L.
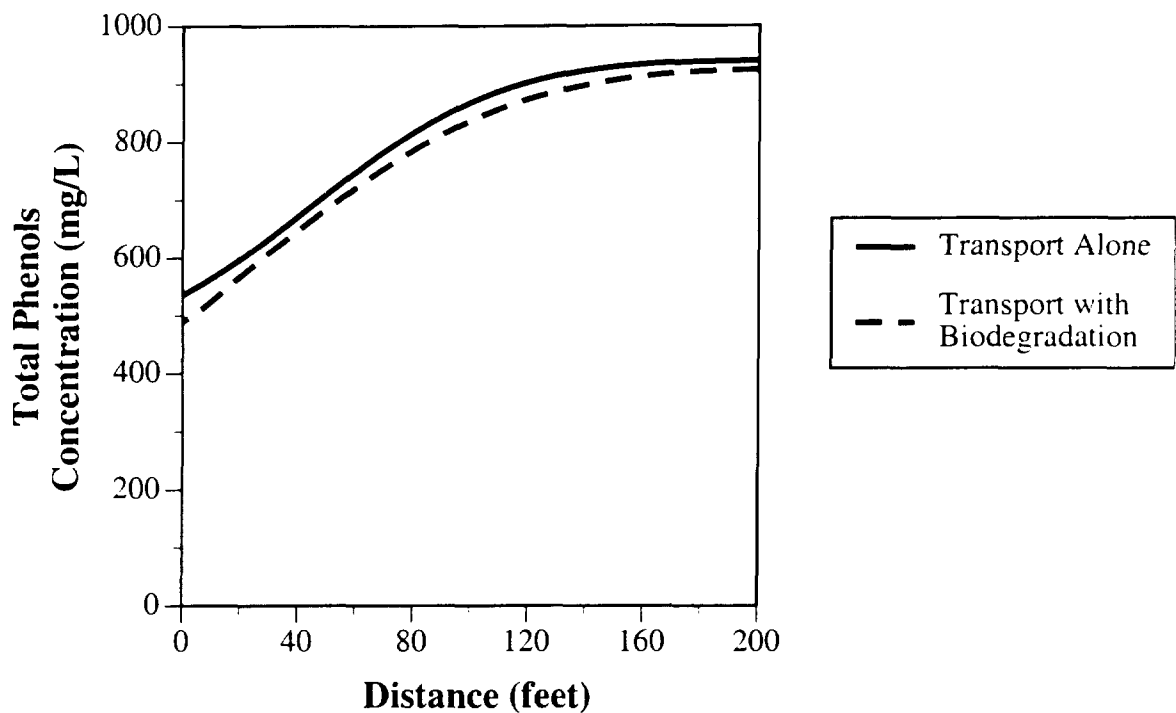
Figure 1-5. Predicted effect of anaerobic biodegradation on transect phenols concentrations 2 years after the influent concentration reductions.
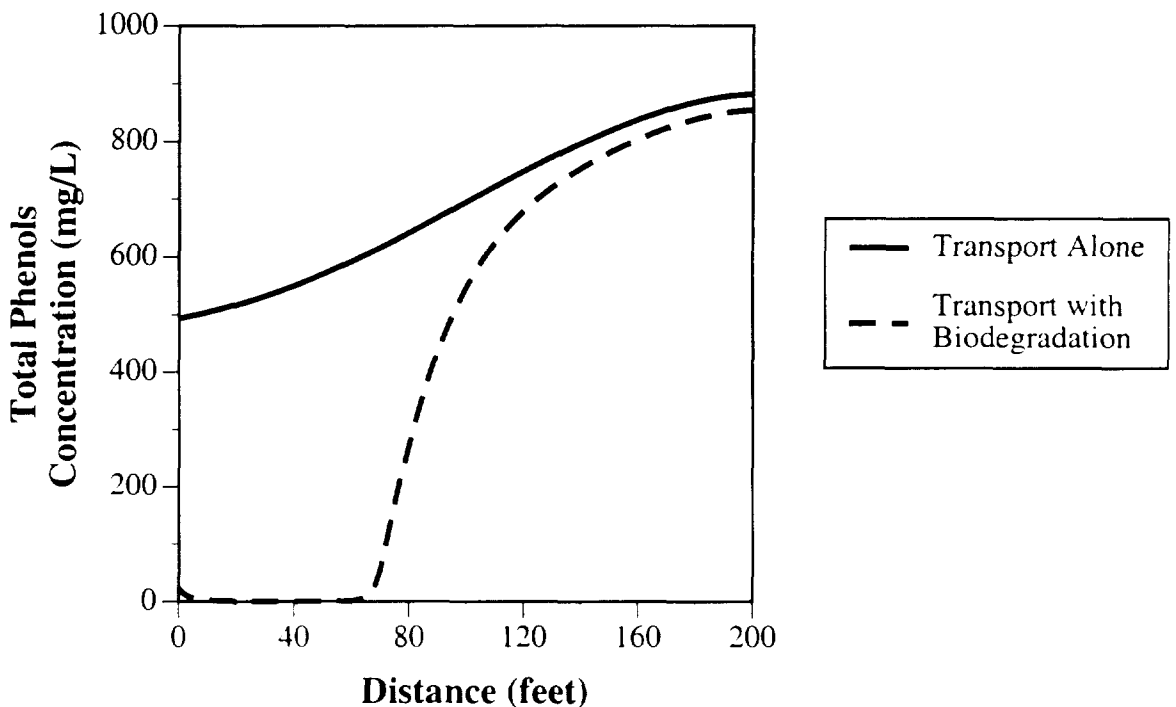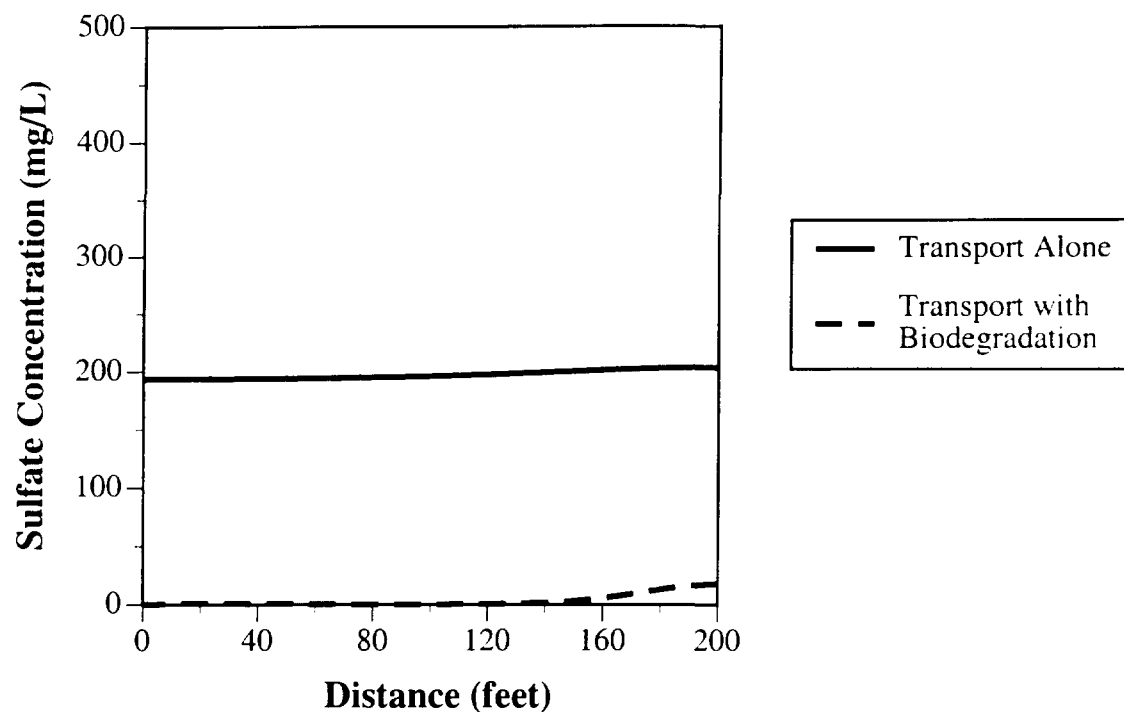

Figure 1-6. Predicted effect of anaerobic biodegradation on transect phenols concentrations 4 years after the influent concentration reductions.
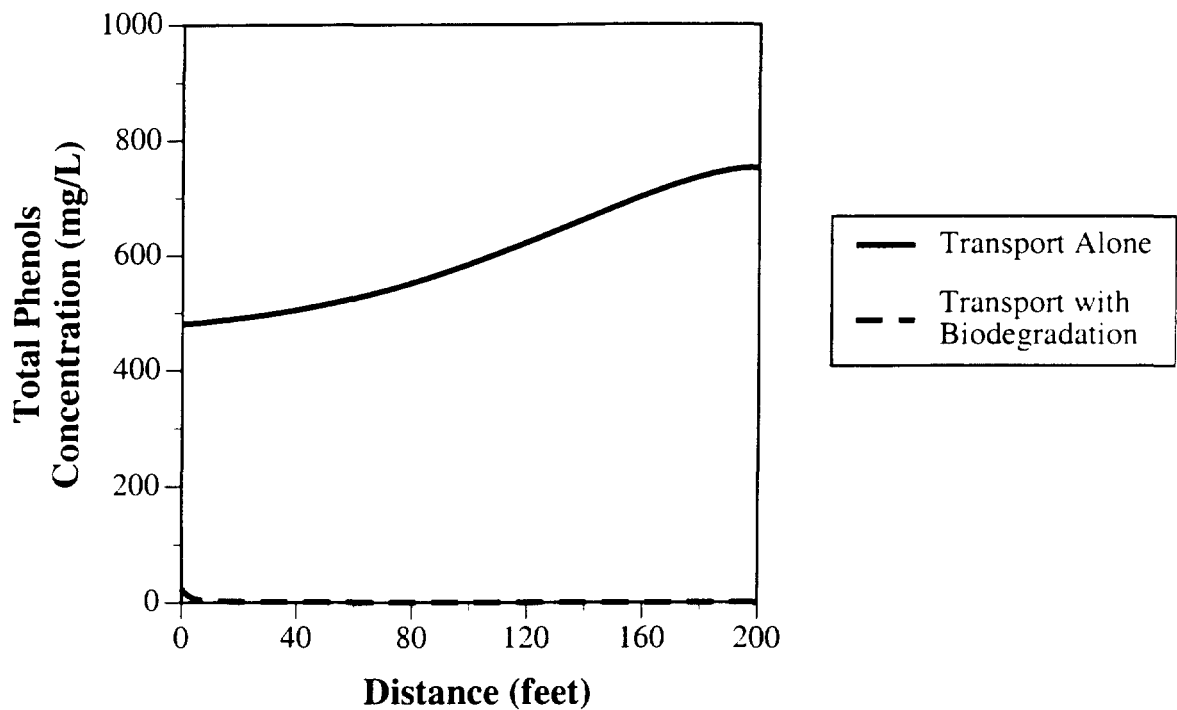
Figure 1-7. Predicted effect of anaerobic biodegradation on transect phenols concentrations 6 years after the influent concentration reductions.
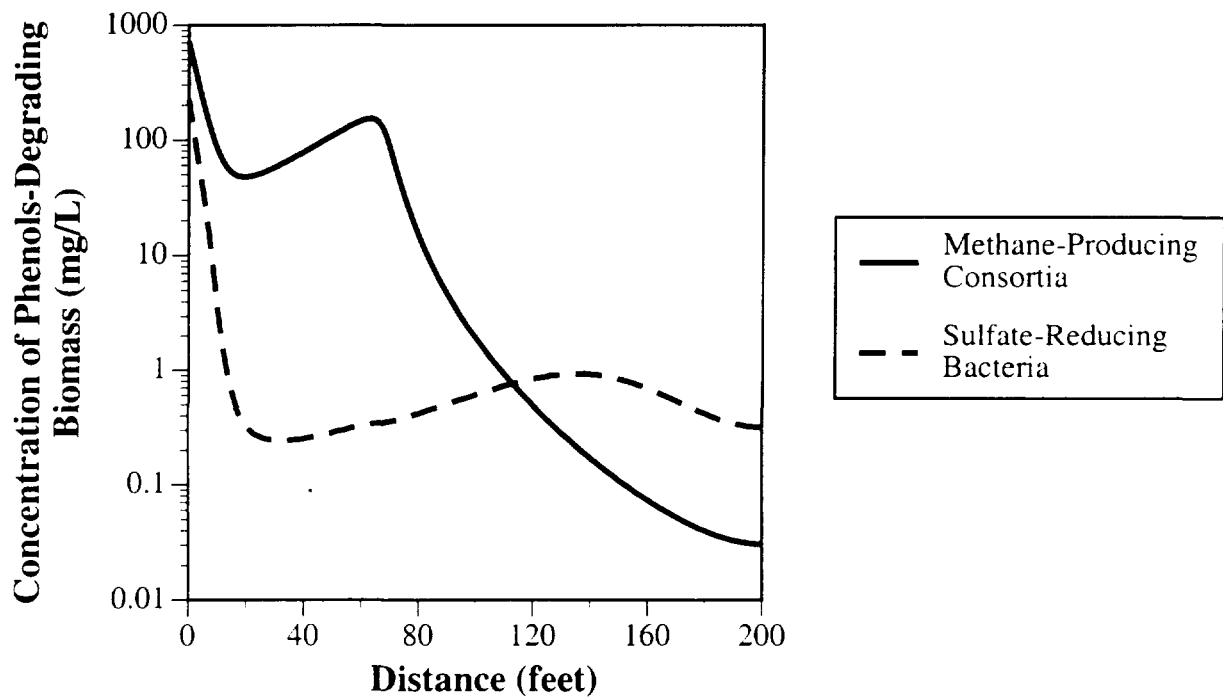
Figure 1-8. Predicted distribution of phenols-degrading biomass 4 years after the influent concentration reductions.

Figure 1-9. Predicted effect of anaerobic biodegradation on transect sulfate concentrations 4 years after the influent concentration reductions.

Technical Consideration of
Impracticability of Remedial Alternative 4

Appendix 5-F

Technical Consideration of Impracticability of
Remedial Alternative 4
Waukegan Manufactured Gas and Coke Plant Site
Waukegan, Illinois

1.0 Background

The evaluation of the soil and groundwater data from the Waukegan Manufactured Gas and Coke Plant Site (the WCP site) indicate that implementation of Remedial Alternative 4 to attain Illinois Class I or II Groundwater Quality Standards[1] in the sand aquifer is technically impracticable. These findings are further confirmed by the results of the RI and post-RI studies, as summarized in Section 2.

This appendix is not intended to be a technical impracticability (TI) evaluation for ARAR waiver, as described in Guidance for Evaluating the Technical Impracticability of Ground-Water Restoration, EPA 540-B-93-080, dated September 1993 (the EPA TI Directive). Specifically, issues related to establishment of Alternative Concentration Limits (ACLs) or Alternative Groundwater Quality Standards (AGQSs) are not addressed. Instead, this appendix provides technical considerations concerning impracticability of Remedial Alternative 4.

For the sake of consistency, the format of this consideration is developed consistent with the EPA TI Directive. This directive identifies the components of a formal TI evaluation as:

- **TI Levels:** Specific ARARs or media cleanup standards for which the TI waiver is sought.

- **TI Extent:** Spatial area over which the TI decision will apply.

- **Conceptual Model:** Conceptual model that describes site geology, hydrology, groundwater contamination sources, transport and fate.

- **Engineering TI:** Evaluation of the restoration potential of the site including data and analyses which support any assertion that attainment of ARARs or media cleanup standards is technically impracticable from an engineering perspective. At a minimum, this generally should include:

  - A demonstration that contamination sources have been identified and have been, or will be, removed and contained to the extent practicable;

  - An analysis of the performance of any ongoing or completed remedial actions;

  - Predictive analyses of the time frames to attain required cleanup levels using available technologies; and

  - A demonstration that no other remedial technologies (conventional or innovative) could reliably, logically, or feasibly attain the cleanup levels at the site within a reasonable time frame.

- **Cost:** Estimates of the cost of the technically impracticable remedy option, including construction, operation, and maintenance costs.

- **Additional Information:** Any additional information or analyses that EPA deems necessary for the TI evaluation.

The TI consideration components are discussed below.

2.0 TI Levels

Under Remedial Alternative 4, consideration of site-specific conditions indicates that relevant and appropriate standards for the site groundwater would be the Illinois requirements for maximum practical restoration of beneficial use of the groundwater. For this analysis the site groundwater is considered to be either Class I or II Groundwater (35IAC620). Illinois Class I standards are equivalent to MCLs. The Class II groundwater classification is for groundwater within 10 feet of the (original) ground surface or groundwater in a filled area.

The water table of the WCP sand aquifer is located only 4 to 5 feet below the ground surface. In addition, the peninsula on which the site is located has been created over the last 100 years by breakwater-induced sediment accumulation and direct filling operations.

In subsequent discussions, the TI consideration focuses on groundwater risk-drivers, including arsenic and phenol. Class I and II Groundwater Quality Standards for arsenic and phenol are listed in Table 3-4. However, this consideration applies to all constituents in site groundwater for which a Class I or II standard exists. It should be noted that an existing city ordinance prohibits use of groundwater, and Remedial Alternatives 2 and 3 include institutional control to prohibit installation of wells and/or use of groundwater.

3.0 TI Extent

The impacted groundwater is part of the WCP site sand aquifer. This aquifer is recharged by surface infiltration. The groundwater discharges to Lake Michigan to the east, Waukegan Harbor to the west/southwest, and to the Breakwater area to the southeast, as shown in Appendix 2-B, Figure B-10. The extensive RI/FS investigations have provided an adequate basis to determine various groundwater recharge-discharge zones, as delineated in Appendices 2-B and 2-C. For the purposes of this discussion, the sand aquifer located within and downgradient of the WCP site is considered collectively as the Remedial Alternative 4 TI extent.

4.0 Conceptual Model

Section 2 and Appendices 2-B and 2-C provide detailed information about the site hydrogeological conceptual model. The key findings of Section 2 are:

- Past aqueous discharges during operation and demolition of the plant were advected downward and impacted various portions of the sand aquifer. Due to the flushing effect of clean infiltrating water and naturally-occurring bioremediation, more contaminants have been removed from the shallow portion of the sand aquifer than the deep portion. This is confirmed by the current vertical distribution of the contaminants in groundwater, as shown on Figures 2-12 through 2-16.

- The available data demonstrate that the highly impacted zone of groundwater is located within about 5 feet of the base of the sand aquifer.

- The shallow aquifer is recharged by infiltrated water, which in turn, is discharged to Lake Michigan to the east, Waukegan Harbor to the west/southwest, and to the Breakwater area to the southeast (Appendix 2-B, Figure 2-B-10).

- The groundwater divide has shifted in the past toward the east due to the eastward movement of the shoreline (Figure 2-A-2, Appendix 2-C, and Figure 2-C-6). The beach accretion is further discussed in Appendix 2-A. Currently, the groundwater divide is located approximately along the eastern boundary of the site (Figure 2-4).

5.0   Engineering TI

Consistent with the EPA TI Directive, the technical consideration of impracticability of Remedial Alternative 4 for the WCP site is supported by the following factors.

5.1   Source Removal and Elimination

The EPA TI Directive states that the TI evaluation should include a demonstration that contamination sources have been identified and have been, or will be, removed and contained to the extent practicable. Based on the extensive investigations conducted during the RI and post-RI work, the vertical and horizontal extents of sources and releases are adequately characterized (Sections 6 though 8 of the RI, as summarized in Section 2 of this FS). The aqueous discharge sources associated with the plant operation and demolition ended with plant demolition and site grading in 1972 (Section 2).

Furthermore, as discussed in Section 6, under the Remedial Alternatives 2, 3 or 4, impacted vadose soils will be removed, stabilized in-situ, and capped to control infiltration. These actions collectively will lead to the near elimination of sources of groundwater contamination.

5.2   Effects of Biodegradation and Flushing

The EPA TI Directive states that a TI evaluation should include an analysis of the performance of any ongoing or completed remedial actions. As discussed in Section 2 and Appendices 2-C, 2-F, and 2-G, there is ongoing natural attenuation of the contaminants due to flushing of the sand aquifer and aerobic and anaerobic biodegradation. The removal effects of flushing and biodegradation are

especially apparent in the upper 20 feet of the sand aquifer, as demonstrated by the 1997 beach transect groundwater sample data (Figures 2-12 through 2-17).

Prior to the beach growth and flushing by clean infiltration, the upper 20 feet of the sand aquifer is believed to have been impacted at concentrations similar to those observed in its lower 5 feet (Figures 2-12 through 2-17). Clean water infiltration into the aquifer flushed contaminants from the upper 20 feet of the sand aquifer and biodegradation accelerated the removal of contaminants as the flushing progressed. Based on beach infiltration rate of 33.7 inches per year (Figure 2-B-9), in the past 25 years, more than seven pore volumes of the sand aquifer under the beach has been flushed. The hydraulics of this favorable condition are illustrated by the flow-lines depicted in Appendix 2-C, Figure 2-C-13, that clearly demonstrate the ongoing flushing of the shallow portion of the sand aquifer by clean infiltrated water. The biological mechanisms acting to reduce the concentrations of degradable compounds are described in Appendices 2-F and 2-G.

As 1997 beach transect data indicate, approximately twenty five years of flushing and biological activity reduced the contaminant concentrations considerably. For example, the maximum total phenols in the upper 20 feet of the sand aquifer is 0.64 mg/L, compared to 1,100 mg/L in its lower 5 feet (Figure 2-16). Similar orders-of-magnitude differences are displayed by arsenic where the maximum concentration in the upper 20 feet of the sand aquifer is 1.13 mg/L, compared to 63 mg/L in its lower 5 feet (Figure 2-14). These improvements are indicative of the effectiveness of the ongoing natural attenuation in the upper 20 feet of the sand aquifer. The data also indicate while significant concentration reductions have occurred, Class I or II Groundwater Quality Standards have not been attained, even after flushing of more than seven pore volumes. For example, despite a four-orders-of magnitude attenuation, the total phenols concentrations in five out of 13 groundwater samples from the upper 20 feet of the beach transect exceeded the Class I and II standard of 0.1 mg/L (Figure 2-16). Similarly, despite a two-orders-of-magnitude attenuation, arsenic concentrations in eight of out of 13 groundwater samples from the upper 20 feet of the beach transect exceeded the Class I standard of 0.05 mg/L, while six out of eight samples exceed Class II standard of 0.2 mg/L (Figure 2-14).

Under Remedial Alternative 4, the impacted zone of the sand aquifer must be remediated to Class I or II Groundwater Quality Standards. The removal rate of an extraction system in this portion (the lower 5 feet) of the aquifer would be expected to be slower than the rate displayed by natural processes in the upper 20 feet of the sand aquifer. As a result, achieving concentration reductions similar to those in the upper 20 feet of the sand aquifer would require high pumping rates. Also, as suggested by the above data, attaining Class I or II Groundwater Quality Standards may require an excessive number of extracted pore volumes. This may render the remedy infeasible, when

considering the fact that the removal efficiency of pumping activities drops after the first few pore volume extractions.

5.3   Time Frame

The EPA TI Directive states that a TI evaluation should include predictive analyses of the time frames to attain required cleanup levels using available technologies. As EPA national surveys of the pump-and-treat operations[2] indicate, extraction operations are characterized by diminishing removal rates. This implies that after the early periods of removal, extraction operations have little or no effect on the concentration of the targeted groundwater contaminants. This indicates that attaining stringent cleanup standards are not expected within a reasonable period of time, if ever.

Under Remedial Alternative 4, it is assumed that at least 15 pore volumes must be flushed, for a remedy duration in excess of 75 years. The majority of the removal of non-retarded compounds is expected to occur within the first few pore-volume flushings. Retarded compounds may persist through many pore volume flushings and will be extracted very slowly. This means that after the first flushing rounds most compounds will have low to negligible removal rates, but will still exceed groundwater standards (see Section 5.2). Given the uncertainty concerning these removal rates, attainment of Class I or II Groundwater Quality Standards can easily require substantially more time than the assumed 75 years. This conclusion is supported by the following factors:

- The above-cited EPA national surveys have indicated that actual durations of a pump-and-treat operations far exceed the initially predicted cleanup time frames.

- Site-specific evidence shows that significant attenuation of groundwater contaminants in the sand aquifer is feasible, as demonstrated by the 1997 beach transect data. However, biodegradation and flushing in the upper 20 feet of the sand aquifer have not been able to attenuate groundwater contaminant concentrations to Class I or II standards after an estimated seven pore volumes have been flushed..

As noted in other EPA Region V remedy decisions[3], a pumping period of 25 years is considered to represent, for practical purposes, perpetuity. At this stage, the time frame for Remedial Alternative 4 to attain Class I or II Groundwater Quality Standards should be viewed as perpetual and indefinite.

5.4   Alternative Remedial Technologies

The EPA TI Directive states that a TI evaluation should include a demonstration that no other remedial technologies (conventional or innovative) could reliably, logically, or feasibly attain the cleanup levels at the site within a reasonable time frame. As noted in Section 4, a wide array of alternative technologies has been investigated for groundwater remediation. Certain alternatives were further subjected to treatability studies, as discussed in Section 1 of the FS Report. Among all the investigated remedies, targeted groundwater extraction supplemented by natural attenuation, as discussed under Remedial Alternatives 2 and 3, is the only reliable, logical, and feasible alternative.

5.5   Site-Specific Technical Challenges

Under Remedial Alternative 4, the contaminated groundwater can be removed and treated. However, there are significant technical constraints that would require investments in time and effort beyond typical pump-and-treat operations. First, the impacted groundwater above Class I or II Groundwater Quality Standards covers an area in excess of 50 acres. Capture and flushing of such a large volume within a credible time frame requires high pumping rates. This form of recovery would draw large quantities of surface water compared to the quantity of the impacted groundwater. This added volume not only reduces the removal efficiency of the extraction process, but also introduces complications in long-term treatment and disposal of the extracted water. Second, given the characteristics of the groundwater at the site, a complex array of treatment processes will be required to achieve a water quality suitable for discharge to the surface water or to the NSSD. Treatment must include different and multiple units to treat metals, volatiles, ammonia, and dissolved solids. Third, the expected duration of the remedial action is indefinite, which imposes significant uncertainty about long-term reliability of the extraction/treatment system.

Given the extent of the required capture zone of the extraction system, the volume of extracted water, the complexity of the required treatment train, and operational issues related to the disposal of treated water, the maintenance of the system would be problematic and require significant efforts. These problems collectively would yield a system that requires continuous repairs and corrections, with questionable reliability. Under such a condition, as stated by EPA[4], Remedial Alternative 4 should be considered as "infeasible from an engineering perspective."

The above site-specific conditions indicate that Remedial Alternative 4 is not technically feasible.

6.0 Cost

Consistent with the EPA TI Directive, cost evaluations are conducted for Remedial Alternative 4. Cost implications provide further evidence in support of the infeasibility to attain Class I or II Groundwater Quality Standards under Remedial Alternative 4. As stated by EPA[5]: "Cost, although a factor, is not generally the major factor in the determination of TI. However, a remedial alternative that is feasible might be deemed technically impracticable if it could only be accomplished at an inordinate cost." More recently, EPA has stated that[6]: "Cost should generally play a subordinate role in determining practicability from an engineering perspective. Engineering practice is in reality ultimately limited by costs, hence cost may legitimately be considered in determining what is ultimately practicable."

Table 5-7 provides the cost estimates for Remedial Alternative 4. The total estimated present worth cost of $100 million (about $80 million for the groundwater portion of the remedy) is computed based on a 50-year period. The above evaluations indicate that the presumed 50-year period is likely to be underestimated. The computed cost of Remedial Alternative 4 will be exceeded if the extraction period is extended beyond the 50-year period.

The computed $100 million is an inordinate cost, especially when compared to total costs associated with other feasible and protective Remedial Alternatives (Section 5). In accordance with the EPA TI Directive, this cost comparison provides further support for the technical infeasibility of Remedial Alternative 4.

7.0 Regulatory Precedent

The effectiveness of pump-and-treat systems similar to Remedial Alternative 4 in creating hydraulic containment and reducing the concentrations of contaminants in groundwater is well established. However, the TI of such remedies to attain MCLs (Class I) or Class II Groundwater Quality Standards, has been observed at numerous sites. The EPA TI Directive provides detailed background on national surveys that have concluded that groundwater restoration at many sites is technically impracticable. These surveys include the EPA's "Considerations in Ground Water Remediation at Superfund Sites;" OSWER Directive 9335.4-03, dated 1989; and EPA's "Evaluation of Ground-Water Extraction Remedies," EPA/540/89/054, Volumes 1-3, dated 1989.

At many superfund sites, the TI of the groundwater restoration is recognized where the extraction alternatives are either eliminated, or their performance standards have been modified. Superfund site examples include: Ciba-Geigy McIntosh Plant, Alabama (EPA IV), Brodhead Creek, Stroudsburg, Pennsylvania (EPA III), Newport Dump Site, Wilder, Kentucky (EPA IV), DuPont OU1, Newport, Delaware (EPA III), Dover Gas Light, Dover, Delaware (EPA III), and Northern Engraving Corp, Sparta, Wisconsin (EPA V).

7.1   Brodhead Creek Site

Among the above-cited Superfund sites, the Brodhead Creek Site is especially noted due to its similarity to the WCP site. Brodhead Creek Site main characteristics are summarized below:

Operational History: Brodhead Creek Site is a former coal gasification plant which operated along the west bank of Brodhead Creek in the Borough of Stroudsburg, Monroe County, Pennsylvania, from approximately 1888 to 1944.

Soil Stratigraphy: This site is underlain by a number of strata (in descending order): fill, floodplain deposits, stream gravels, silty sands, and bedrock. The principal shallow water-bearing strata at this site are the stream gravel unit and the underlying silty sand unit.

Confined Impacted Zone: The waste product for this site included coal-tar that was primarily composed of PAHs. The coal-tar was placed in an open pit located on the property. Currently, soil contamination due to coal tar-related compounds is limited both horizontally and vertically to the stream gravel unit.

Residual Groundwater Contamination: The Brodhead Creek Site Record of Decision (ROD), dated June 30, 1995, presents the selected remedy for residual coal tar contamination and dissolved phase groundwater contamination in the subsurface soils (Operable Unit 2, OU-2) at the Brodhead Creek Site. OU-2 covers dissolved phase groundwater contaminants (concentrations less than the free coal tar[7]).

A review of the above site characteristics indicates a strong similarity between the WCP and Brodhead Creek sites. These similarities include correspondence between the two sites operational histories, stratigraphies, confined contamination distributions and residual (i.e., dissolved phase) contaminants. Therefore, the remedy decision of Brodhead Creek OU-2 should provide a regulatory precedent for the evaluation of Remedial Alternative 4.

The Brodhead Creek OU-2 ROD states that:

"After careful consideration of the requirements of CERCLA, the detailed analysis of the alternatives, and public comments, EPA has selected Alternative 1, No Further Action, for Operable Unit Two (i.e., contaminated groundwater) at this site. Although the hypothetical ingestion of on-site ground water reveals a risk above 1x10⁻⁴, this scenario is highly unlikely. As mentioned previously, several Site specific constraints limit the practicability of using the groundwater at the Site as a drinking water source."

The ROD further states that:

"Therefore, EPA is waiving the federal MCLs for drinking water and Pennsylvania's 'background' ARAR on the basis of technical impracticability. Use of the 'technical impracticability' (TI) waiver is appropriate when attainment of an ARAR would be illogical or infeasible from an engineering perspective and therefore would be 'impracticable.'"

The above ROD provides a strong precedent for recognition of the technical infeasibility of Remedial Alternative 4 at the WCP site.

End Notes

[1] Title 35 Illinois Administrative Code 640.240

[2] EPA, "Considerations in Ground Water Remediation at Superfund Sites," OSWER Directive 9335.4-03, dated 1989; and EPA, "Evaluation of Ground-Water Extraction Remedies," EPA/540/89/054, Volumes 1-3, dated 1989.

[3] GZA-Donohue, "Feasibility Study for Groundwater Treatment," Bofors Nobel Superfund Site, Muskegon, Michigan, 1989, page 14.

[4] 55 Fed. Reg. 30798 (Proposed Rule, Friday, July 27, 1990)

[5] NCP Section 300.430(f)(1)(ii)(C)(3)

[6] 55 Fed. Reg. 8666-01 (Final Rule, March 8, 1990)

[7] In an earlier ROD issued on March 29, 1991, EPA selected an interim remedial action to address the free coal tar areas of the subsurface soils (Operable Unit 1). This interim remedy included installation of extraction wells and injection wells in the free coal tar areas of the subsurface soil.